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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
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EXECUTIVE SUMMARY

Stock

Common thresher sharks (*Alopias vulpinus*) along the west coast of North America are seasonally distributed in coastal waters from British Columbia, Canada to central Baja California, Mexico. Juvenile common thresher sharks tend to remain in shallow, nearshore areas over the continental shelf, especially within the Southern California Bight (SCB), which is an important nursery area. The distributions of common and bigeye thresher sharks are thought to overlap partially, with bigeye thresher sharks generally exploiting deeper waters. In contrast, there relatively little overlap in the distributions of common and pelagic thresher sharks.

In this assessment, common thresher sharks along the west coast of North America are assumed to be a single, well-mixed stock. This assumption is supported by their genetics, tagging data, and seasonal movements. The mitochondrial genetic sequences of common thresher sharks from California waters are not significantly different from Oregon-Washington waters but both are significantly different from other sampling locations, noting that there have not been any published comparisons with samples from Mexico. There is also no evidence of pupping and nursery grounds outside of the SCB. Tags from common thresher sharks tagged in the SCB have been returned from California, USA, and Baja California, Mexico. There is also unlikely to be substantial interchange of individuals between this stock and other common thresher shark stocks because the geographically closest stock is likely to be along the west coast of Chile.

Fisheries

The history of fisheries for this stock of common thresher sharks in USA waters is not well known prior to the 1970s but small amounts of catch were recorded by a variety of USA commercial and recreational fisheries. The most important USA commercial fishery for common thresher sharks is the swordfish/shark drift gillnet (USDGN) fishery, which started in 1977 - 1978. Although the primary targets were initially common thresher and shortfin mako sharks, fishermen soon switched to primarily targeting swordfish because of substantially higher ex-vessel prices. Fishing operations of the USDGN fishery have been heavily regulated to reduce adverse interactions with other fisheries, fishing mortality of common thresher sharks, and incidental bycatch of marine mammals and sea turtles. Secondarily, nearshore set gillnets and small-mesh drift gillnets (USSN) occasionally catch young-of-year and juvenile common thresher sharks as bycatch. There is also a small USA recreational fishery in Southern California (USREC) that targets adult common thresher sharks but catches are usually relatively low.

The historically most important fishery for common thresher sharks in Mexico waters was the Mexico drift gillnet (MXDGN) fishery, which started in 1986. The fishing gear and operations of this fishery were similar to the USDGN fishery, with swordfish and pelagic sharks as the primary targets. The number of MXDGN vessels began to decline in the mid-1990s as vessels began converting to longline gear. The MXDGN fishery has been prohibited since 2010 by Mexico federal regulations. The Mexico artisanal (MXART) fishery operates from small boats called pangas, using various nearshore gears that are set and hauled by hand, along the entire Pacific coast of Mexico. The size and history of this fishery is poorly known but it has likely existed since the early 20th century. Only a small portion of pangas are allowed to fish for sharks. For example, there were 50 shark permits for this fishery in Baja California in 1998, representing about 180 out of more than 2000 pangas in total.

There are no historical nor current fisheries along the west coast of Canada that target common thresher sharks and bycatch appears to be rare. There are also no known historical nor current fisheries that target this stock of common thresher sharks in international waters and bycatch is expected to be minimal, given the largely coastal distribution of this population.

Fishery Removals

Fishery removals by eight fishing fleets based on country, fishing gear, and season were included in this assessment (Table ES.1). These included five USA fleets (F1: USDGN, F2: USDGNs2, F3: USSN, F4: USREC, and F5: USRECs2) and three Mexico fleets (F6: MXDGNLL, F7: MXDGNLLs2, and F8: MXART). The annual estimated removals for the eight fleets are shown in Fig. ES.1.

Estimates of USA commercial landings of common thresher sharks by gear during 1969 – 1980 and 1981 – 2014 were obtained from the CALCOM (http://calcomfish.ucsc.edu) and PacFIN (http://pacfin.psmfc.org) databases respectively. Several types of net gears in the databases could not be clearly separated into DGN and SN gears. The catch from these unidentified net gears were aggregated and then subdivided into DGN and SN gears based on the seasonal proportion of catch for DGN versus SN gears during representative periods. Some of the commercial landings for common thresher sharks were also likely recorded as unspecified sharks. A correction to the estimated removals by USA fisheries for this misreporting of species was performed by estimating the proportion of unspecified shark landings that was likely to be common thresher sharks. The proportion of common thresher sharks that were discarded at sea as dead fish was also estimated from observer records of the USDGN and USSN fisheries and used to expand the removals of the USDGN, USDGNs2, and USSN fleets.

Until recently, shark landings in Mexico were not reported by species. Therefore, the fishery removals for Mexico fisheries were estimated from annual reports of state-specific aggregated shark (Tiburon) landings from the Instituto Nacional de Pesca (INAPESCA) that were available from 1976 through 2013. Subsequently, the proportion of common thresher sharks in the aggregated shark catch of the Pacific coast of Baja California was estimated for specific periods since 1976. The estimated common thresher shark catches were then separated into seasonal catches by the MXDGN, MXLL, and MXART fisheries. The estimated removals from 1976 – 2013 for each fleet were extrapolated to the 1969 – 1975 period and 2014 in order to match the 1969-2014 assessment period. All common thresher sharks caught were assumed to be retained by the Mexico fisheries.

Table ES.1. Description of fleets and abundance indices in the base case model.

Fleet ID	Short name	Fleet description
		Fleets with removals
F1	USDGN	USA swordfish/shark pelagic drift gillnet fishery for seasons 1, 3, and 4. Removals from USA miscellaneous fisheries for these seasons were included into this fleet.
F2	USDGNs2	USA swordfish/shark pelagic drift gillnet fishery for season 2. Removals from USA miscellaneous fisheries for season 2 were included into this fleet.
F3	USSN	USA nearshore set gillnet and small-mesh drift gillnet fishery for all 4 seasons.
F4	USREC	USA recreational fishery for seasons 1, 3, and 4. Catch units in number of fish.
F5	USRECs2	USA recreational fishery for season 2. Catch units in number of fish.
F6	MXDGNLL	Mexico swordfish/shark pelagic drift gillnet fishery for seasons 1, 3, and 4. Removals from the Mexico pelagic longline fishery for these seasons were included in this fleet.
F7	MXDGNLLs2	Mexico swordfish/shark pelagic drift gillnet fishery for season 2. Removals from the Mexico pelagic longline fishery for this season were included in this fleet.
F8	MXART	Mexico coastal artisanal fishery with mixed gillnet and longline gears. Also known as the panga fishery.
		Abundance indices inputted as surveys
S1	USDGN8284	Standardized annual index of relative abundance of sub-adult/adult common thresher sharks based on logbooks from the USA swordfish/shark pelagic drift gillnet fishery during 1982 – 1984.
S2	USDGN9200	Standardized annual index of relative abundance of sub-adult/adult common thresher sharks based on logbooks from the USA swordfish/shark pelagic drift gillnet fishery during 1992 – 2000.
S3	USDGN0113	Standardized annual index of relative abundance of sub-adult/adult common thresher sharks based on logbooks from the USA swordfish/shark pelagic drift gillnet fishery during 2001 – 2013.
S4	USSN8593	Standardized annual index of relative abundance of primarily age-0 common thresher sharks based on logbooks from the USA nearshore set gillnet and small-mesh drift gillnet fishery during 1985 – 1993.
S5	USSN9414	Standardized annual index of relative abundance of primarily age-0 common thresher sharks based on logbooks from the USA nearshore set gillnet and small-mesh drift gillnet fishery during 1994 – 2014.
S6	USJUV0614	Standardized annual index of relative abundance of juvenile common thresher sharks from a coastal longline survey conducted by the Southwest Fishery Science Center during 2006 – 2014.

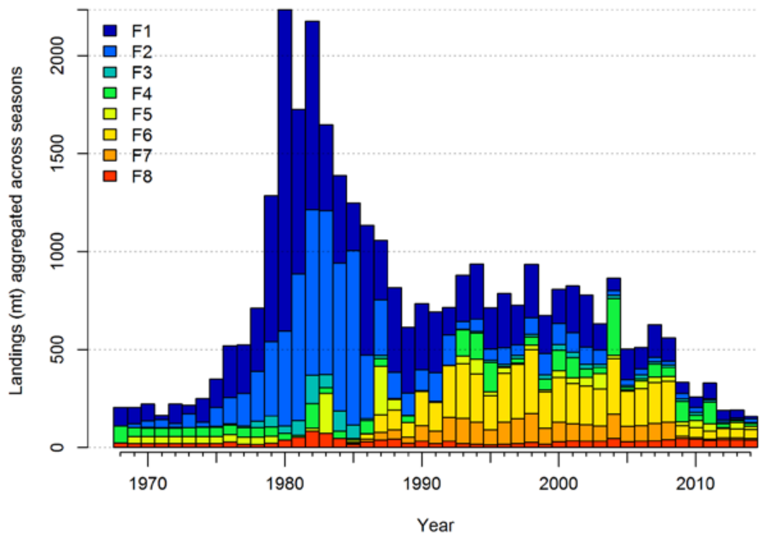

Figure ES.1. Estimated annual fishery removals by fleet. See Table ES.1 for a description of the fleets.

Data and Assessment

This is the first stock assessment of common thresher sharks along the west coast of North America that incorporates information from all fisheries exploiting the population. The Stock Synthesis modeling platform (v3.24U) was used to conduct the analysis and estimate management quantities. The base case model began in 1969, assuming that the stock was at equilibrium prior to 1969 in a near unfished state, and ended in 2014, which was the last year that data were available. Each fishing year was divided into 4 seasons (1: Feb-Apr; 2: May-Jul; 3: Aug-Oct; and 4: Nov-Jan). The assessment model was sex-specific due to differences in biology between genders and assumed that the sex ratio at birth was 1:1. Sex-specific growth was estimated within the model. A low fecundity stock-recruitment relationship was used in the model because common thresher sharks produce only a few pups per litter, with relatively little variability in litter size, and pups are born at a relatively large size, which suggested that common thresher sharks have lower potential productivity and a more direct connection between stock size and recruitment than for teleosts. The shape parameter, β, of the stock-recruitment relationship was also estimated within the model.

The model included eight fishing fleets that operated in USA and Mexico waters (see above in Fishery Removals and Table ES.1). Five abundance indices from fishery-dependent fisheries and one abundance index from a fishery-independent survey were available (Table ES.1). However, the survey abundance index (USJUV0614) was not fit in the base case model. Length composition data were available for the majority of the fleets and were fit in the base case model, with the exception of the MXDGNLL fleet. Conditional age-at-length data from two USA fleets (USDGN and USSN) were also fit in the base case model.

A large number of alternative model configurations were investigated to develop the base case model, which provided a realistic but parsimonious description of common thresher shark population dynamics based on the best available scientific information. The base case model reflected the best aspects of these exploratory models. Overall, the base case model appeared to have converged to a global minimum; while fitting the observed data well, with plausible model processes and parameters that were within reasonable bounds.

Reproductive Capacity and Output

In this assessment, the reproductive capacity of the population was calculated as the number of mature female sharks (i.e., spawning abundance) rather than spawning biomass, because the size of mature female sharks did not appear to affect the number of pups produced (i.e., larger female sharks did not produce more pups). The reproductive output of the stock (i.e., the number of pups produced by the stock) was calculated using four pups produced per year per mature female shark.

In the base case model, the estimated number of mature female common thresher sharks under unfished conditions was 88,200 sharks (95% CI: 69,500 – 107,000 sharks) with a reproductive output of 352,900 pups (95% CI: 278,000 – 427,800 pups) (Fig. ES.2). The start of targeted commercial fishing in 1977 – 1978 was quickly followed by a large increase in fishery removals, peaking in the early 1980s (Fig. ES.1). These relatively large removals resulted in the number of mature female sharks declining quickly to approximately 35,200 sharks (95% CI: 21,300 – 49,100 sharks) in 1985. Over the next decade, the number of mature female sharks continued to decline but at a substantially slower rate, likely due to the management of the USDGN fishery during this period. The historical low estimate occurred in 1995, with 26,800 mature female sharks (95% CI: 15,000 – 38,600 sharks). After 1995, the reproductive capacity gradually increased over the past two decades. In 2014, the terminal year of the assessment model, the estimated number of mature female sharks reached 83,300 sharks (95% CI: 49,500 – 117,100 sharks) with a reproductive output of 333,100 pups (95% CI: 198,000 – 468,300 pups) (Table ES.2).

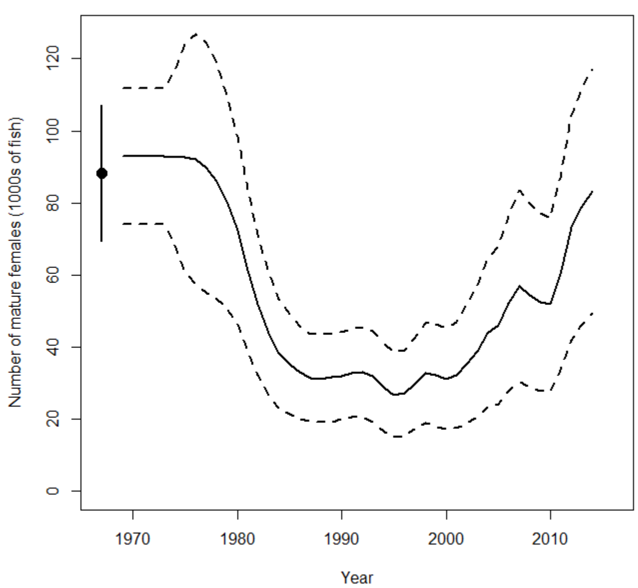

Figure ES.2. Estimated number of mature female sharks in Q2 (Feb – Apr). Dashed lines indicate 95% confidence intervals; and closed circle and error bar indicate estimated quantities and 95% confidence intervals under unfished conditions, respectively.

Depletion of the stock was estimated as the number of mature females in the second quarter (*S*) for a specific year divided by the number of mature females under unfished conditions (S_0) because the reproductive output of the stock (i.e., number of pups produced) was dependent on the number of mature females and not on the biomass of the female sharks. Therefore, the estimated depletion followed the same trajectory as the number of mature female sharks, albeit scaled to S_0 (Fig. ES.3).

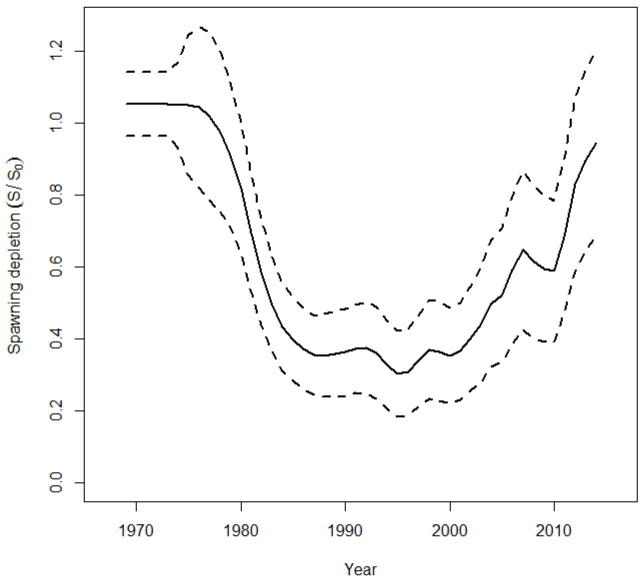

Figure ES.3. Estimated depletion of the stock (S/S_0). Dashed lines indicate 95% confidence intervals.

Table ES.2. Recent estimates of total biomass (Q1, age-1+), biomass and number of mature female sharks in Q2, depletion (S/S_0), recruitment, and fishing intensity (1-SPR) estimated in the base case model. Reproductive output in number of pups is: 4 * number of mature females.

Year	Total biomass age-1+ (t)	Biomass of mature female sharks (t)	Number of mature female sharks (1000s)	Depletion (S/S_0)	Number of recruits (1000s)	Fishing intensity (1-SPR)
2005	16041.0	4753.2	46.1	0.523	49.50	0.262
2006	16216.0	5274.6	52.1	0.591	150.51	0.256
2007	17630.4	5808.1	57.0	0.646	125.69	0.291
2008	18960.3	5788.9	54.4	0.616	87.62	0.264
2009	19996.8	5750.0	52.5	0.595	113.05	0.161
2010	21518.0	5794.9	51.9	0.588	119.32	0.120
2011	23198.6	6402.2	60.3	0.683	86.68	0.138
2012	24346.1	7481.2	73.2	0.830	126.48	0.080
2013	25985.6	8158.4	78.9	0.894	46.49	0.084
2014	26499.2	8707.9	83.3	0.944	88.47	0.076

Recruitment

The estimated recruitment and stock-recruitment relationship were generally consistent with the biology of the stock and assumptions in the base case model. Unfished recruitment was estimated to be 77,100 sharks ($\log(R_0)$ = 4.345). The estimated recruitment fluctuated substantially during the assessment period (1969 – 2014), ranging from a low of 40,700 sharks (95% CI: 23,300 – 58,100 fish) in 1989 to a high of 150,500 sharks (95% CI: 86,400 – 214,600 fish) in 2006 (Fig. ES.4). Overall average recruitment during the assessment period was approximately 73,700 sharks but there appeared to be a period of relatively low recruitment from 1985 – 1995, with average recruitment at 56,700 sharks. In contrast, a more recent period from 2006 – 2012 had substantially higher recruitment, averaging approximately 115,600 sharks.

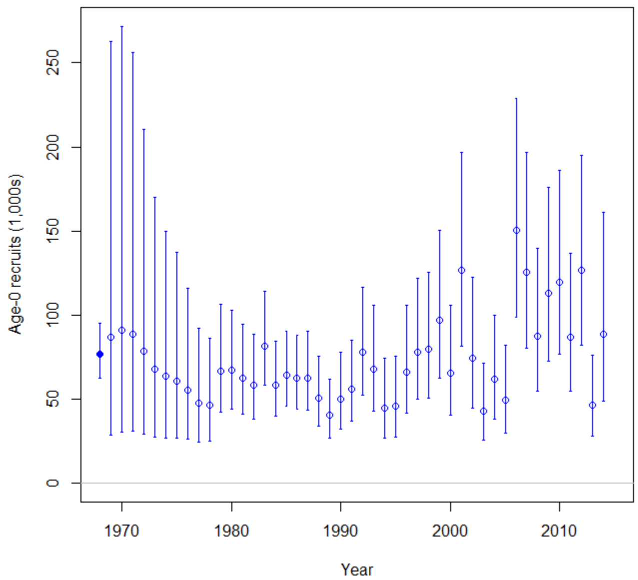

Figure ES.4. Estimated recruitment time series in the base case model. Error bars indicate 95% confidence intervals; and closed circle indicates recruitment under unfished conditions, respectively.

Reference Points

The current USA fishery management plan for USA West Coast fisheries associated with highly migratory species uses status determination criteria (SDC) for common thresher sharks that are based on maximum sustainable yield (MSY), with overfishing occurring if the estimated current fishing mortality or a reasonable proxy exceeds the maximum fishing mortality threshold (MFMT) defined as F_{MSY} or a reasonable proxy; and the stock declared in an overfished condition if current spawning biomass is less than the minimum stock size threshold (MSST) defined as $(1\text{-}M)^*B_{MSY}$, when $M \leq 0.5$ and M is the instantaneous rate of natural mortality. Based on an unpublished assessment of the USA portion of the stock, a harvest guideline of 340 t was established using the alternative optimum yield (OY) control rule for vulnerable species (i.e., 0.75*MSY).

For the base case model of this assessment, the estimated MSY for this stock was 806.5 t (95% CI: 614.7 – 998.3 t), and the number of mature female sharks at MSY was estimated to be 43,500 sharks (95% CI: 34,600 – 52,400 sharks), with a reproductive output of 174,000 pups (95% CI: 138,300 – 209,700 pups) (Table ES.3). The fishing intensity (1-SPR; where SPR is the spawning potential ratio) corresponding to MSY was estimated at 0.39 (95% CI: 0.37 – 0.40). Based on these estimates, the MFMT was 0.39 (using 1 – SPR_{MSY} as a proxy for F_{MSY}) and the MSST was 35,700 mature female sharks.

Table ES.3. Estimated reference points for the base case model.

	Estimate (95% CI)	Units
Unfished conditions		
Number of mature female sharks (spawning abundance) (S_0)	88.2 (69.5 – 107.0)	1000s of sharks
Reproductive output	352.9 (278.0 – 427.8)	1000s of pups
Summary biomass at age-1+ (B_0)	28,096 (21,768 – 34,424)	Metric tons
Recruitment at age-0 (R_0)	77.1 (60.7 – 93.5)	1000s of sharks
MSY-based reference points		
MSY	806.5 (614.7 – 998.3)	Metric tons
Number of mature female sharks at MSY (spawning abundance) (S_{MSY})	43.5 (34.6 – 52.4)	1000s of sharks
Minimum stock size threshold (MSST) (1-M)* S_{MSY}	35.7 (28.4 – 43.0)	1000s of sharks
Reproductive output at MSY	174.0 (138.3 – 209.7)	1000s of pups
Fishing intensity at MSY (1-SPR_{MSY})	0.39 (0.37 – 0.40)	NA

Status of the Stock

The estimated fishing intensity (1-SPR) on common thresher sharks off the west coast of North America is currently relatively low at 0.08 (average of 2012 – 2014) and substantially below the estimated overfishing threshold (MFMT), with (1-SPR_{1214})/(1-SPR_{MSY}) at 0.21 (Table ES.4 and Fig. ES.5). Similarly, the estimated number of mature female sharks in 2014 (S_{2014}) for this stock is at 94% of its unexploited level and is substantially larger than the estimated MSST, with S_{2014}/MSST at 2.33 (Table ES.4 and Fig. ES.5). Thus, this stock of common thresher sharks is unlikely to be in an overfished condition nor experiencing overfishing.

The stock experienced a relatively large and quick decline in the late 1970s and early 1980s, soon after the onset of the USA swordfish/shark drift gillnet fishery, with spawning depletion dropping to 0.4 in 1985. The population appeared to have stabilized in the mid-1980s after substantial regulations were imposed. Over the past 15 years, the stock began recovering relatively quickly and is currently close to an unexploited level.

Uncertainty

This assessment explicitly estimated the model uncertainty due to uncertainty in parameter estimates, which were reported as confidence intervals for key parameters and management quantities. In addition, a suite of sensitivity runs were used to explore the uncertainty associated with alternative model specifications and examine the sensitivity of important model outputs to different model assumptions. These included alternative assumptions about fishery removals, initial conditions, stock-recruitment, life history like natural mortality, growth, maturity, and fecundity; and alternative data sources and weightings. The most important sources of uncertainty were related to the reproductive biology and stock-recruitment of the stock.

Besides the base case model, the status of the stock was also examined under three alternative states of nature, based on alternative reproductive biology and two alternative stock-recruitment relationships. These alternative states of nature addressed the most important sources of uncertainty identified in the sensitivity analysis. The estimated management quantities from models assuming these alternative states of nature all indicated that this stock of common thresher sharks is unlikely to be in an overfished condition nor experiencing overfishing (Table ES.4 and Fig. ES.6).

Decision Table

The same four states of nature used to examine stock status were also used in model projections: the base case model; alternative reproductive biology; and two alternative stock-recruitment relationships.

Ten-year forecasts for each state of nature were calculated based on three future removal scenarios: 1) average catch for 2012 – 2014 in the base case model; 2) 2 * the average catch for 2012 – 2014 in the base case model; and 3) total annual catch of USA swordfish/shark drift gillnet and recreational fisheries at the 340 t PFMC harvest guideline and remaining fisheries at their average catch for 2012 – 2014.

A decision table with these future removal scenarios and alternative states of nature is provided in Table ES.5. For all states of nature and removal scenarios, the adult population is expected to continue increasing and stock depletion is expected to continue improving over the next several years. For the base case and alternative stock-recruitment states of nature, the adult population starts to decline after several years because the fisheries on common thresher sharks primarily catch juvenile and sub-adult sharks and a lag of several years is needed before changes are evident in the adult population. For the alternative reproductive biology model, a lag longer than 10 years (timespan of the forecasts) is needed before changes in the adult population are evident, given the older median age-at-maturity.

Research and Data Needs

In this stock assessment, several critical assumptions were made based on limited supporting data and research. There are several research and data needs that if satisfied could improve future assessments, including:

1. The reproductive biology of this stock of common thresher sharks requires further research.
2. The survey design and protocols of the USA juvenile thresher shark survey should be re-examined and improved.
3. Catch and catch-at-size estimates from USA fisheries, especially the USA recreational fishery, should be improved.
4. Catch and catch-at-size estimates from Mexico fisheries should be improved.
5. The use of the low fecundity stock recruitment relationship requires further research.

Table ES.4. Summary of reference points and management quantities for the base case and three alternative states of nature. C_{2014} is the estimated fishery removals in metric tons in 2014. 1-SPR_{1214} is the average of the estimated fishing intensity (1-SPR) from 2012 through 2014. Key management quantities for the USA fishery management plan are in bold. Under the current USA fishery management plan, this stock is considered to be in an overfished state if S_{2014}/MSST is <1. Overfishing is considered to be occurring if (1-SPR_{1214})/(1-SPR_{MSY}) is >1.

	Base case	**Alternative reproductive biology (12-years median age-of maturity; biennial; M = 0.0757)**	**Alternative stock-recruitment (z_{frac} = 0.4)**	**Alternative stock-recruitment (z_{frac} = 0.8)**
MSY (t)	806.5	773.8	911.1	833.7
Number of mature female sharks at MSY (S_{MSY}) (1000s of sharks)	43.5	33.9	71.6	32.0
Number of mature female sharks under virgin conditions (SB_0) (1000s of sharks)	88.2	67.4	134.3	70.6
Minimum stock size threshold (MSST) (1-M)*S_{MSY}	35.7	27.9	58.8	26.3
Fishing intensity at MSY (1-SPR_{MSY})	0.39	0.39	0.34	0.45
C_{2014}/MSY	0.20	0.21	0.17	0.19
S_{2014}/S_{MSY}	1.91	1.44	1.81	2.13
S_{2014}/S_0	0.94	0.72	0.97	0.97
S_{2014}/MSST	2.33	1.75	2.21	2.59
(1-SPR_{1214})/(1-SPR_{MSY})	0.21	0.20	0.16	0.21

Table ES.5. Decision table of 10-year projections for the base case and three alternative states of nature based on two major axes of uncertainty: 1) reproductive biology and 2) stock-recruitment relationship; and three future catch scenarios: 1) average catch for 2012 – 2014; 2) 2 * average catch for 2012 – 2014; and 3) total annual catch of USA swordfish/shark drift gillnet and recreational fishery at the 340 t PFMC harvest guideline and remaining fisheries at average catch for 2012 – 2014. Note that the total removals shown for scenario 1 and 2 are approximate (±4 t) because catches by the USA recreational fishery are in numbers of fish and conversion to catch in weight depends on the estimated growth for each model.

			Base model		**Alternative reproductive biology (12-years median age-of maturity; biennial; M = 0.0757)**		**Alternative stock-recruitment (z_{frac} = 0.4)**		**Alternative stock-recruitment (z_{frac} = 0.8)**	
Forecast catch scenario (see legend)	Year	Total removals (t)	Number of mature females (1000s of fish)	Depletion	Number of mature females (1000s of fish)	Depletion	Number of mature females (1000s of fish)	Depletion	Number of mature females (1000s of fish)	Depletion
Average catch 2012-14	2015	182.5	89.8	1.02	98.0	0.73	138.4	1.03	74.2	1.05
	2016	183.2	92.7	1.05	97.7	0.72	141.7	1.06	76.9	1.09
	2017	183.7	96.2	1.09	97.9	0.73	146.2	1.09	80.1	1.13
	2018	184.1	94.6	1.07	105.1	0.78	143.4	1.07	78.9	1.12
	2019	184.3	90.9	1.03	117.1	0.87	137.5	1.02	75.6	1.07
	2020	184.2	89.3	1.01	124.0	0.92	135.1	1.01	73.6	1.04
	2021	183.7	86.2	0.98	129.8	0.96	130.8	0.97	69.9	0.99
	2022	183.2	82.9	0.94	137.7	1.02	126.1	0.94	66.2	0.94
	2023	182.6	80.1	0.91	142.9	1.06	122.4	0.91	63.0	0.89
	2024	182.0	78.7	0.89	148.5	1.10	120.9	0.90	61.0	0.86
2X average catch 2012-14	2015	365.5	89.7	1.02	98.0	0.73	138.3	1.03	74.1	1.05
	2016	367.1	92.0	1.04	97.6	0.72	141.0	1.05	76.2	1.08
	2017	368.1	94.9	1.08	97.8	0.73	145.0	1.08	78.8	1.12
	2018	368.9	92.7	1.05	104.9	0.78	141.5	1.05	76.9	1.09
	2019	369.0	88.3	1.00	116.9	0.87	134.9	1.00	73.0	1.03
	2020	368.4	85.9	0.97	123.5	0.92	131.7	0.98	70.1	0.99
	2021	367.2	82.2	0.93	129.2	0.96	126.7	0.94	65.8	0.93
	2022	365.8	78.5	0.89	136.7	1.01	121.8	0.91	61.7	0.87
	2023	364.5	75.6	0.86	141.5	1.05	118.0	0.88	58.4	0.83
	2024	363.4	74.3	0.84	146.7	1.09	116.6	0.87	56.6	0.80
Harvest guideline 340 t for F1, F2, F4 & F5	2015	440.7	89.8	1.02	98.0	0.73	138.4	1.03	74.1	1.05
	2016	440.7	91.6	1.04	97.6	0.72	140.6	1.05	75.8	1.07
	2017	440.7	94.0	1.07	97.8	0.73	144.0	1.07	77.9	1.10
	2018	440.7	91.3	1.04	104.8	0.78	140.1	1.04	75.6	1.07
	2019	440.7	86.8	0.98	116.6	0.87	133.3	0.99	71.5	1.01
	2020	440.7	84.5	0.96	123.2	0.91	130.2	0.97	68.8	0.97
	2021	440.7	80.9	0.92	128.6	0.95	125.4	0.93	64.7	0.92
	2022	440.7	77.6	0.88	135.9	1.01	120.8	0.90	60.9	0.86
	2023	440.7	75.1	0.85	140.4	1.04	117.5	0.87	58.0	0.82
	2024	440.7	74.2	0.84	145.2	1.08	116.6	0.87	56.6	0.80

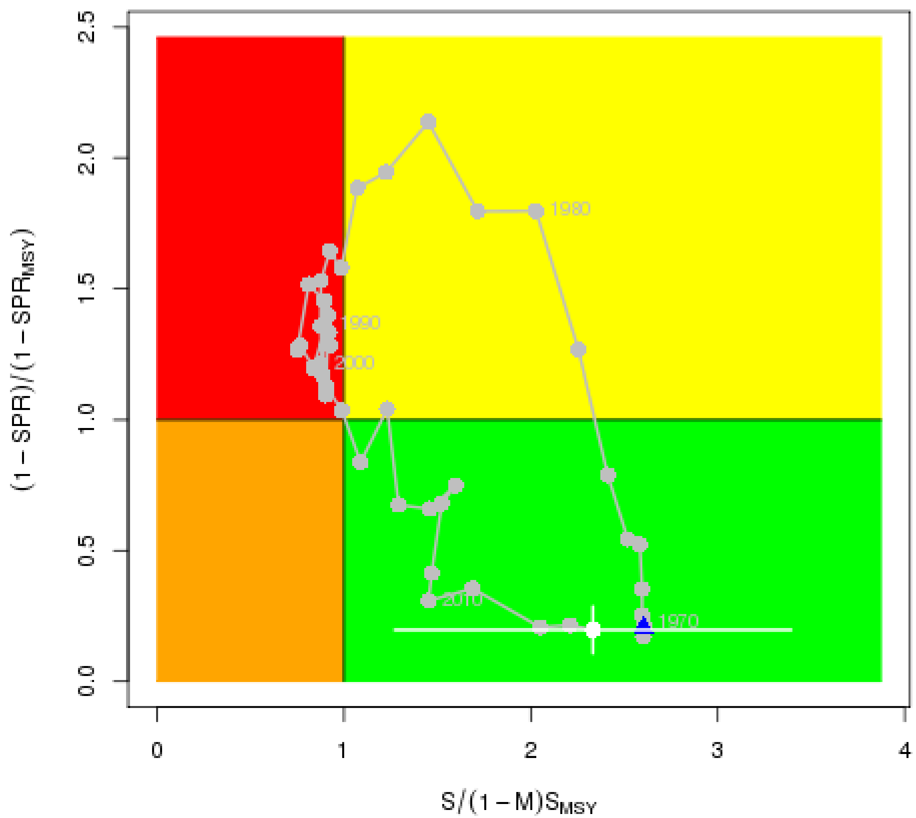

Figure ES.5. Kobe time series plot of the ratio of spawning abundance (S; number of mature female sharks) relative to the minimum stock size threshold reference point (MSST; (1-M)*S_{MSY}) and ratio of the fishing intensity (1-SPR) relative to the maximum fishing mortality threshold (MFMT; 1-SPR_{MSY}) for the base case model. Values for the start (1969) and end (2014) years are indicated by blue triangle and white circle, respectively. White lines indicate the 95% confidence intervals. Grey numbers indicate selected years.

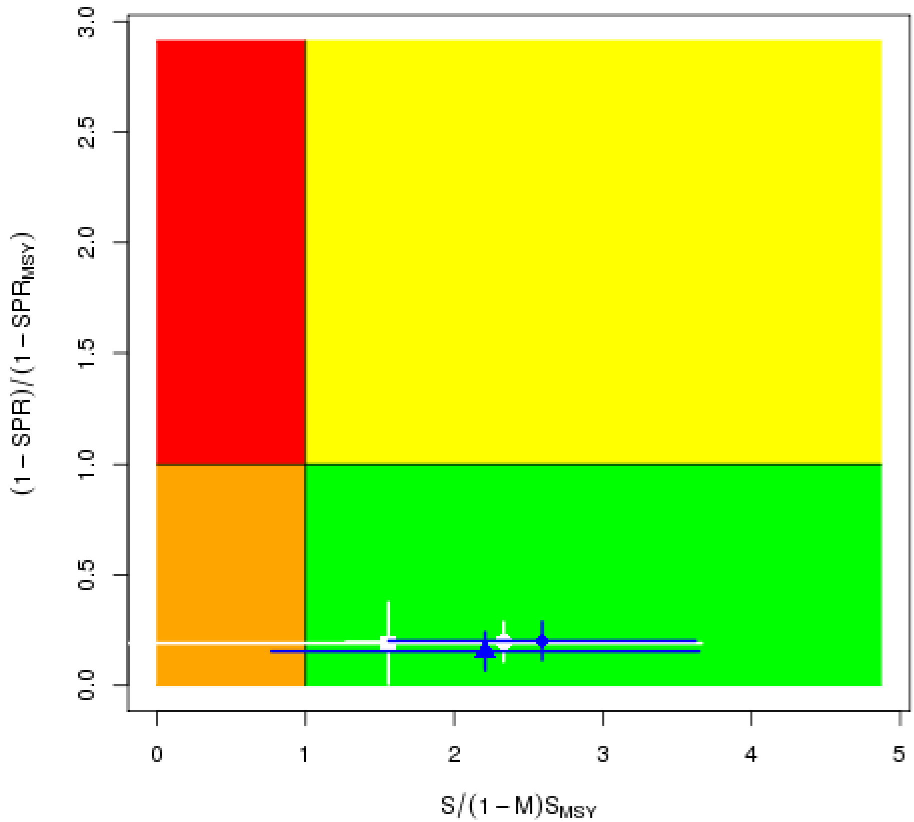

Figure ES.6. Kobe plot of the ratio of spawning abundance (S; number of mature female sharks) relative to the minimum stock size threshold reference point (MSST; (1-M)*S_{MSY}) and ratio of the fishing intensity (1-SPR) relative to the maximum fishing mortality threshold (MFMT; 1-SPR_{MSY}) for the end year (2014) of the base case model (white circle) and three alternative states of nature: 1) alternative reproductive biology with a biennial reproductive cycle, 12 years median age-at-maturity, and natural mortality of 0.0757 (white square); 2) alternative stock-recruitment with z_{frac} of 0.4 (blue triangle); and 3) alternative stock-recruitment with z_{frac} of 0.8 (blue diamond). White and blue lines indicate the respective 95% confidence intervals.

1. Introduction

There are three recognized species of thresher sharks around the world's oceans: 1) common (*Alopias vulpinus*); 2) bigeye (*A. superciliosus*); and 3) pelagic (*A. pelagicus*) thresher sharks. These three species are distinguished by the highly elongated dorsal lobe of their caudal fins, which approaches their body length (Compagno 1984). Thresher sharks typically feed on schooling fishes and squids (Preti et al. 2012), and use their long caudal fin as a whip to stun and kill prey (Aalbers et al. 2010). All three species are caught by various international and USA fisheries, and are highly regarded for human consumption.

Common thresher sharks can be easily distinguished from bigeye thresher sharks but pelagic thresher sharks have been misidentified as common thresher sharks (Smith et al. 2008a). Bigeye thresher sharks are distinguished by very large eyes that have orbits that expand onto the dorsal surface of the head, and a deep horizontal groove on the side of the head (Compagno 1984). Common thresher sharks are distinguished by labial folds around the mouth, and a difference in skin color above the base of the pectoral fin (Compagno 1984).

All three species of thresher sharks are large pelagic sharks but exhibit differences in distribution, and are thought to have different ecological niches (Smith et al. 2008a). Common and bigeye thresher sharks are distributed circumglobally in the Atlantic, Indian, and Pacific Oceans and the Mediterranean Sea, while pelagic thresher sharks are restricted to the Indian and Pacific Oceans (Gruber and Compagno 1981; Compagno 1984). Compared to bigeye and pelagic thresher sharks, common thresher sharks are relatively more coastal, occurring primarily within 40-75 miles of land, over continental and insular shelves and slopes, and occupy cooler, more temperate waters (Compango 1984; Smith et al. 2008a). Pelagic thresher sharks are distributed primarily in warmer, oceanic waters but misidentification of pelagic thresher sharks as common thresher sharks have resulted in less reliable habitat distribution information (Smith et al. 2008a). Bigeye thresher sharks are thought to exploit deeper waters in warm temperate and tropical areas, making forays into mesopelagic depths to at least 500 m (Smith et al. 2008a).

This is the first stock assessment of common thresher sharks along the west coast of North America that incorporates information from all fisheries exploiting the population throughout its distribution. Previously, an unpublished population growth rate (PGR) analysis of common thresher sharks, using only data from USA fisheries, resulted in an estimated local maximum sustainable yield (LMSY) of 450 t (PFMC 2003). However, the LMSY was considered to be a minimal estimate because the analysis did not include any information from Mexico fisheries exploiting the same population (PFMC 2003). The PGR analysis was dependent on estimates of the intrinsic rate of increase for common thresher sharks, which indicated that common thresher sharks were likely to be moderately productive with productivity similar to blue and shortfin mako sharks (Smith et al. 2008b). The PGR analysis also assumed that the population was at an unfished state in 1981 (start of the CPUE series) even though the largest commercial fishery for this stock of common thresher shark began in 1977 – 1978 (Hanan et al. 1993). Given the drawbacks of the previous analysis, a collaboration was initiated between scientists from the USA and Mexico to conduct a stock assessment of this common thresher shark population throughout its entire distribution along the west coast of North America.

1.1 Distribution, biology, and life history

1.1.1 Distribution and seasonal movements

Along the west coast of North America, common thresher sharks are seasonally distributed in coastal waters from British Columbia, Canada to central Baja California, Mexico. The highest concentration of common thresher sharks occur in the Southern California Bight (SCB), which extends from Point Conception, California to Cabo Colonet, Mexico (Hanan et al. 1993; Smith et al. 2008a). The distributions of common and bigeye thresher sharks are thought to overlap partially, with bigeye thresher sharks generally exploiting deeper waters (Smith et al. 2008a). In contrast, there relatively little overlap in the distributions of common and pelagic thresher sharks, except for El Nino years, when the distribution of pelagic thresher sharks shift northwards (Smith et al. 2008a).

Seasonal movements of common thresher sharks are not well known but they are thought to move northward from Baja California into Southern California in early spring (Hanan et al. 1993). Large, adult sharks are then hypothesized to continue northwards to as far north as British Columbia, with the reverse movement occurring in winter (Hanan et al. 1993). Juvenile sharks tend to remain in shallow, nearshore areas over the continental shelf, especially within the SCB, which is an important nursery area (Holts and Bedford 1989; Cartamil et al. 2010).

1.1.2 Stock structure

In this assessment, common thresher sharks along the west coast of North America are assumed to be a single, well mixed stock, which is supported by their genetics and seasonal movements. Trejo (2005) analyzed a 1,082 bp segment of the mitochondrial DNA control region and found that common thresher sharks from California waters were not significantly different from sharks in Oregon-Washington waters but both were significantly different from all other common thresher shark stocks, noting that there were no samples from Mexico. In addition, there is no evidence of pupping and nursery grounds outside of the SCB and common thresher sharks migrate seasonally along the coastal waters from Baja California to as far north as British Columbia, Canada (Smith et al. 2008a). Limited tagging data also supports the assumption that this is a local population of common thresher sharks limited to the coastal waters of the west coast of North America (Cartamil et al. 2010; Cartamil et al. 2011a). There is also unlikely to be substantial interchange of individuals between this stock and other common thresher shark stocks because the geographically closest stock is likely to be along the west coast of Chile. Due to species misidentification, thresher sharks previously reported as common thresher sharks from many other parts of the Pacific Ocean have turned out to be pelagic thresher sharks after using genetic tools to identify the species (J. Hyde, Southwest Fisheries Science Center, NOAA Fisheries, personal communication; Velez-Zuazo et al. 2015).

1.1.3 Reproductive biology

Common thresher sharks are ovoviviparous, where after the absorption of the yolk sac, developing fetuses consume eggs still developing in the uterus (Smith et al. 2008a). The reproductive cycle is seasonal, with mating thought to occur in summer and pupping occurring in spring after a gestation period lasting 9 months (Smith et al. 2008a). Common thresher sharks have small litter sizes, usually giving birth to two to four pups (Gubanov 1978; Cailliet et al. 1983; Bedford 1992; Natanson and Gervelis 2013) but litter sizes of up to seven have been recorded off Spain (Moreno et al. 1989).

Previous studies on the reproductive biology of common thresher sharks have resulted in inconsistent conclusions about their fecundity, which may reflect differences between stocks. Smith et al. (2008b) thought that common thresher sharks in the eastern North Pacific produced two female pups per year (i.e., an annual reproductive cycle with four pups per litter, assuming an equal sex ratio at birth), when they estimated intrinsic rates of increase for several pelagic shark species. This was supported by Castro (2009), who suggested that thresher sharks exhibited an annual reproductive cycle based on concurrent vitellogensis and gestation coupled with continuous ovulation. However, Natanson and Gervelis (2013) suggested that common thresher sharks in the western North Atlantic had at least a biennial reproductive cycle with an average litter size of 3.7 pups.

There also appear to be substantial differences in the estimated median age of maturity between common thresher sharks in the eastern North Pacific and the western North Atlantic. Smith et al. (2008a) estimated that the female common thresher sharks in the Pacific reach maturity at about 5.3 years of age (~160 cm FL). However, Natanson and Gervelis (2013) estimated that the median age of maturity for female common thresher sharks in the western North Atlantic was 12 years of age (~216 cm FL).

1.1.4 Growth

Common thresher sharks are large pelagic sharks with sexually dimorphic growth and intermediate to relatively rapid growth rates (Cailliet et al. 1983; Smith et al. 2008a; Gervelis and Natanson 2013). Sharks are aged by examining band pairs consisting of one opaque and one translucent band in vertebral cross-sections (Cailliet et al. 1983). There have been three studies on the growth of common thresher sharks, with two in the eastern North Pacific (Cailliet et al. 1983; Smith et al. 2008a) and one in the western North Atlantic (Gervelis and Natanson 2013). The initial growth curves by Cailliet et al. (1983) lacked older, larger samples and resulted in high estimates of asymptotic length. Smith et al. (2008a) fitted additional age-length data to a von Bertalanffy growth curve and estimated the following parameters for male and female common thresher sharks – Male: L_∞ = 221.5 cm, K = 0.189 y^{-1}, and t_0 = -2.08 y; Female: L_∞ = 247.3 cm, K = 0.124 y^{-1}, and t_0 = -3.35 y, where L_∞ is the asymptotic length in fork length, K is the rate coefficient, and t_0 is the theoretical age at length 0. Common thresher sharks in the western North Atlantic appeared to follow a relatively similar growth curve albeit with slightly higher asymptotic lengths (Gervelis and Natanson 2013).

1.2 Historical and current fisheries in USA waters

The history of common thresher shark fisheries along the west coast of the USA is not well known prior to the 1970s but small amounts of catch were recorded by the California Department of Fish and Game (CDFG) prior to the 1970s (Pearson et al. 2008). Prior to the 1970s, some species of shark were exploited in the USA for food, vitamin-rich liver oil, pet food, leather, curios, and reduction to protein and fertilizer but common thresher sharks do not appear to have been heavily exploited prior to the 1970s (Holts 1988).

Demand for common thresher sharks as food began to increase in the mid-1970s on the west coast of the USA, together with other shark species like Pacific angel and shortfin mako sharks (Holts 1988). Ex-vessel prices for shark meat rose sharply due to this demand and common thresher sharks became one of several shark species with important west coast fisheries. For example, ex-vessel prices for thresher sharks rose five-fold between 1977 ($0.29 per pound; $1.13 per pound in 2014 dollars) and 1986 ($1.60 per pound; $3.46 per pound in 2014 dollars) (Holts 1988), which is substantially higher than the average price in 2014 ($0.82 per pound) (PFMC 2015).

The most important USA commercial fishery for common thresher sharks is the swordfish/shark drift gillnet (USDGN) fishery. Secondarily, nearshore set gillnets and small-mesh drift gillnets (USSN) occasionally catch young-of-year and juvenile common thresher sharks as bycatch. Common thresher sharks are also occasionally caught as bycatch by a variety of miscellaneous gears like purse seine and harpoon but catches are usually minimal. Some recreational fishermen in Southern California target adult common thresher sharks but catches are usually relatively low (PFMC 2015).

1.2.1 USA swordfish/shark drift gillnet (USDGN)

The most important commercial fishery for common thresher sharks is the USDGN fishery, which began in 1977 – 1978 (Hanan et al. 1993). The drift gillnet gear was inspired by the occasional catch of pelagic sharks in nearshore gillnets used to target barracuda and white seabass. The nets used by the USDGN fishery have larger mesh size than the nearshore gillnets, and regulations have required a minimum mesh size of 14 inches since 1982 (Hanan et al. 1993).

The USDGN fishery began with about 15 vessels in Southern California but the number of vessels grew rapidly (Hanan et al. 1993). By 1985, the number of California permits for the fishery totaled about 265, with about 35 of those permits limited to areas north of Point Arguello, California (PFMC 2003). Although the initial primary targets were common thresher and shortfin mako sharks, fishermen soon discovered that they could efficiently catch swordfish with the same gear, and switched to primarily targeting swordfish because of substantially higher ex-vessel prices (Hanan et al. 1993). Since those early days, the primary target of the USDGN fishery has been swordfish, with common thresher and shortfin mako sharks being secondary targets.

The USDGN fishery expanded into Oregon and Washington in 1983, when these states began issuing experimental permits for a thresher shark fishery (PFMC 2003). Thresher shark landings for Oregon and Washington remained relatively low until 1986, when 37 vessels landed 293 t dressed weight of common thresher sharks. However, Oregon and Washington closed the experimental fishery in 1989 due to concern over the observed incidental bycatch of marine mammals and sea turtles (PFMC 2003).

Landings of common thresher sharks by the USDGN fishery peaked in 1982 at 1711 t (PFMC 2011a) and have declined since, dropping to approximately 10 t in 2014 (PFMC 2015). The number of USDGN vessels landing fish have also declined from 297 in 1985 (PFMC 2011a) to only 18 vessels by 2014 (PFMC 2015).

Fishing operations of the USDGN fishery have been heavily regulated to reduce adverse interactions with other fisheries, fishing mortality of common thresher sharks, and incidental bycatch of marine mammals and sea turtles (Hanan et al. 1993; PFMC 2003). The timeline of major changes in regulations and operations for the USDGN fishery can be found in Table 1.1. Details of current and historical regulations are provided by Hanan et al. (1993), PFMC (2003), and PFMC (2015). There appeared to be three major periods of fishery operations and regulations: 1) 1977 – 1991; 2) 1992 – 2000; and 3) 2001 – 2014. The first period (1977 – 1991) encompassed the initial expansion of the fishery and the switch from primarily targeting pelagic sharks to swordfish. There were also early attempts at regulating the fishery, which resulted in frequent changes in regulations that included gear restrictions, swordfish catch, swordfish to shark catch ratios, seasonal closures, and time-area closures (Table 1.1). In particular, time-area closures in California were enacted or modified in 1982, 1985, and 1989, which likely affected the catch-per-unit-effort (CPUE) of sharks for this fishery (Urbisci et al. in review). Washington and Oregon also closed their drift gillnet fisheries in 1989. The time-area closures for the USDGN fishery were relatively stable during the second period (1992 – 2000), after the closure period for California was changed to May 1 through August 14 in 1992 (Table 1.1). The second period was a period of decline in the USDGN fishery, with the number of vessels landing fish declining from 119 in 1992 to 72 in 2000 (PFMC 2015). This decline continued in the third period (2001 – 2014), which was marked by the enactment of a large time-area closure in 2001 to protect leatherback turtles (Table 1.1). 1The number of vessels in the USDGN fishery landing fish declined from 61 in 2001 to 18 in 2014 (PFMC 2015).

1.2.2 USA nearshore set gillnet and small-mesh drift gillnet (USSN)

A secondary USA commercial fishery that catches common thresher sharks is the nearshore set gillnet and small-mesh drift gillnet (USSN) fishery in nearshore waters that target species like barracuda, white seabass, and halibut. The key differences between this fishery and the USDGN fishery are that the USSN fishery uses nets with smaller mesh size (typically <10 inches) and fishes in shallow, nearshore waters. Most of the catch and effort of the USSN fishery centers around the SCB but some parts of the fishery operates in nearshore areas as far north as Mendocino, California.

The USSN fishery does not target common thresher sharks but occasionally catches common thresher sharks as bycatch. The USSN fishery predominantly catches young-of-year common thresher sharks because the continental shelf of the SCB is a known nursery area for common thresher sharks (Cartamil et al. 2010).

In 1994, the California Marine Resources Protection Act of 1990 began prohibiting all gillnets and trammel nets within 3 nm of the California mainland and within 1 nm (or waters <70 fathoms deep) of the Channel Islands (Table 1.1). This resulted in the USSN fishery fishing in slightly deeper waters from 1994.

1.2.3 USA recreational (USREC)

Common thresher sharks are a target of the USA recreational fishery, especially in Southern California (Holts et al. 1998). Recreational fishing directed at large pelagic species, including sharks, come from anglers on Commercial Passenger Fishing Vessels (CPFVs) (Hill and Schneider 1999), as well as private vessels departing from sportfishing landings, marinas, and boat ramps. The vast majority of recreationally caught common thresher sharks are caught by anglers on private vessels (>99 %) rather than CPFVs. Captains of CPFVs are required to submit logbooks but not private vessels. Information on recreational fishing from private vessels is obtained using surveys, which are available in a comprehensive coastwide marine recreational fishery database (RecFIN; http://www.recfin.org). Information on common thresher sharks caught by anglers on private vessels is highly limited.

1.3 Historical and current fisheries in Mexico waters

Subsistence fishing for sharks has historically been an important resource for rural communities along the Pacific coast of Mexico but commercial shark fishing in the Gulf of California developed during World War II to provide shark liver oil to the USA (Holts et al. 1998). Three Mexico fisheries have historically been or currently are important fisheries for common thresher sharks: 1) Mexico swordfish/shark drift gillnet (MXDGN); 2) Mexico pelagic longline (MXLL); and 3) Mexico artisanal (MXART) fisheries.

1.3.1 Mexico swordfish/shark drift gillnet (MXDGN)

The historically most important fishery for common thresher sharks in Mexico waters was the MXDGN fishery. A small fleet of MXDGN vessels began fishing for swordfish from Ensenada, Mexico in 1986, and the fleet increased to 31 vessels by 1993 (Holts and Sosa-Nishizaki 1998). Soon after that, the number MXDGN vessels began to decline as vessels began converting to longline gear in the mid-1990s. The MXDGN fishery has been prohibited since 2010 by federal regulations in Mexico (Sosa-Nishizaki 2013). Similar to the USDGN fishery, the primary and secondary targets were swordfish and pelagic sharks respectively (Holts et al. 1998). The fishing gear and operations of this fishery were also similar to the USDGN fishery, except that nets in Mexico could extend to 4.8 km in length whereas nets in the USA were limited to 1 nm (1.8 km). A 50 nm sportsfishing-only zone was established along the Mexico coast in 1983 but commercial fishing operations for sharks continued to be routinely conducted in this zone (Holts et al. 1998).

1.3.2 Mexico pelagic longline (MXLL)

Mexico and international pelagic longline fisheries have operated within 200 nm of the Mexico coast during various periods. From 1967 to 1976, Mexico issued permits to Japanese pelagic longline vessels to fish for swordfish, billfish, and tunas (Holts and Sosa-Nishizaki 1998). After Mexico established its Exclusive Economic Zone (EEZ) in 1976, all longline permits were withheld until 1980. From 1980 to 1990, a Mexico/Japan joint venture program for the longline fishery was established, which targeted swordfish, billfish and tunas (Holts and Sosa-Nishizaki 1998). After the cessation of that program in 1990, no pelagic longline fishing occurred until the mid-1990s, when MXDGN vessels began converting to longline gear. Like the MXDGN fishery, the primary and secondary targets of the current MXLL fishery are swordfish and pelagic sharks respectively. However, the pelagic sharks targeted are primarily blue and shortfin mako sharks instead of common thresher sharks.

1.3.3 Mexico artisanal (MXART)

The MXART fishery operates along the entire Pacific coast of Mexico, and fishes from small boats called pangas, which are small, open boats approximately 7-9 m long powered by an outboard engine (Holts et al. 1998). Hence, the artisanal fishery is also often called the panga fishery. The size and history of this fishery is largely unknown but it has likely existed throughout the 20th century and thought to have exceeded 2000 pangas by the late 1990s (Holts et al. 1998). Only a small portion of the pangas are permitted to fish for sharks. For example, Holts et al. (1998) stated that in the Mexican state of Baja California, there were 50 shark permits for this fishery in 1998, representing about 180 pangas. Pangas can range up to 40 km but usually fish closer to shore. A variety of gears are used, including gillnets and longlines, but the fishing gears are limited by the need to set and haul by hand. The MXART fishery is highly mobile and the pangas can be easily trailered to other locations with better fishing or market prices. Given the nature of the MXART fishery, it is generally difficult to obtain data from this fishery.

1.4 Historical and current fisheries in Canadian and international waters

There are no historical nor current fisheries along the west coast of Canada that target common thresher sharks and bycatch of common thresher sharks appear to be rare (McFarlane et al. 2010). McFarlane et al. (2010) reported some bycatch of bigeye thresher sharks, which may have been misidentified common thresher sharks. However, further enquiry indicated that these reports of bigeye thresher shark bycatch were erroneous due to miscoded unidentified shark species (J. R. King, pers. comm.). There are also no known historical nor current fisheries that target this stock of common thresher sharks in international waters and bycatch is expected to be minimal, given the largely coastal distribution of this population.

1.5 Management history

Common thresher sharks have been managed in USA waters under the fishery management plan (FMP) for highly migratory species (HMS) by the Pacific Fishery Management Council (PFMC)

(PFMC 2003; PFMC 2011b). A summary of major changes in the management history is shown in Table 1.1 and described in more detail in sections 1.2 and 1.3. Most important for this assessment is the implementation and changes to various time-area closures for the USDGN fishery in 1982, 1985, 1989, 1992, and 2001, and the USSN fishery in 1994, which likely affected the catchability and selectivity of these fisheries. Changes in the management and fishing operations of the Mexico fisheries probably also affected their catchability and selectivity but the lack of information on these fisheries, other than catch, during these periods precluded modeling such effects.

A harvest guideline of 340 t is currently in place for common thresher sharks in USA waters, based on an estimate of LMSY from an unpublished analysis (PFMC 2003). Since common thresher sharks are considered a vulnerable species with relatively low productivity, the harvest guideline is derived from the optimum yield (OY) for vulnerable species, which is defined as $0.75*F_{MSY}*B_{MSY}$, or the respective maximum sustainable yield (MSY) proxies. The maximum fishing mortality threshold (MFMT) for common thresher sharks is the ratio $F_{MFMT}/F_{MSY} = 1.0$, or the appropriate MSY proxy. Therefore, the stock is considered to be experiencing overfishing if $F_{current}/F_{MSY} > 1.0$. The maximum stock size threshold (MSST) is the minimum biomass at which recovery measures are to begin. Since common thresher shark has natural mortality (M) of <0.5, $B_{MSST} = (1\text{-}M)*B_{MSY}$, or the appropriate MSY proxy. Therefore, the stock is considered to be overfished if $B_{current} < (1\text{-}M)*B_{MSY}$ or $B_{current}/(1\text{-}M)*B_{MSY} < 1.0$. Landings of common thresher sharks by fisheries along the west coast of the USA have been less than the harvest guideline of 340 t since 1992 (PFMC 2015).

2. Assessment data

The data used for this assessment are summarized in Figure 2.1, and included both fishery-dependent and fishery-independent data. The time period of this assessment was 1969 – 2014 because recorded landings for USA fisheries were unreliable before 1969. In addition, total landings from 1969 through 1976 were relatively minimal before the development of the USDGN fishery. The data were divided into fishing years, which were defined as February 1 to January 31 because fishing operations for the USDGN fishery end on January 31. Each fishing year was further subdivided into four seasons of three months each (1: Feb-Apr; 2: May-Jul; 3: Aug-Oct; and 4: Nov-Jan). Data for the assessment included fishery removals (i.e., catch), abundance indices, length composition, and conditional age-at-length data. The fleet structure of the assessment model consisted of eight fleets based on country, fishing gear, and season; and six abundance indices. See subsections in this section and Table 2.1 for details on the fleet structure and nomenclature.

2.1 Fishery-dependent data

The USA fleets in the assessment model were based on the USDGN, USSN, and USREC fisheries. The catch from a variety of miscellaneous gears like purse seine and harpoon were added to that of the USDGN fishery because the catch was minimal and the size composition of the catch was assumed to be similar to the USDGN fishery. The USDGN and USREC fisheries were further subdivided into separate fleets for season 2, and seasons 1, 3, and 4 because preliminary examination of the size composition data indicated that large adult common threshers were caught by these fisheries in season 2, which is the pupping season. Therefore, the assessment model contained five USA fleets: F1: USDGN; F2: USDGN season 2 (USDGNs2); F3: USSN; F4: USREC; and F5: USREC season 2 (USRECs2) (Table 2.1).

The Mexico fleets in the assessment model were based on the MXDGN, MXLL, and MXART fisheries. However, the catches from the MXLL and MXDGN fisheries were combined because the only data available for the MXLL fishery was catch and anecdotal evidence suggested similar sized common thresher sharks were caught by these fisheries. Similar to the USDGN fishery, the MXDGN fishery was subdivided into separate fleets for season 2, and seasons 1, 3, and 4. Therefore, the assessment model contained three Mexico fleets: F6: Mexico drift gillnet and longline (MXDGNLL); F7: MXDGNLL season 2 (MXDGNLLs2); and F8: MXART (Table 2.1).

2.1.1 Commercial removals

The estimated removals for the eight USA and Mexico fleets are shown in Table 2.2 and Figure 2.2.

2.1.1.1 USA fisheries

Estimates of commercial landings of common thresher sharks from 1981 through 2014 were obtained from the Pacific Fisheries Information Network (PacFIN), a regional fisheries database that manages fishery-dependent information in cooperation with USA West Coast state agencies, and NOAA Fisheries (http://pacfin.psmfc.org). Catch data were extracted by gear type and assigned to the fishing fleets used in the assessment. Several types of net gear recorded in PacFIN could not be clearly separated into USDGN and USSN gears. The catch from these net gears were aggregated and then subdivided into USDGN and USSN gears based on the seasonal proportion of catch for USDGN versus USSN fisheries during three periods (1981-1985; 1986-1993; and 1994-2014). The largest amount of catch for these unknown net gears was 281 t for 1985 season 2, and the amount of catch for these unknown net gears was negligible after 1994. The catch from miscellaneous gears was added to the USDGN (F1) and USDGNs2 (F2) fleets.

Estimates of commercial landings of common thresher sharks from 1969 through 1980 were obtained from the CALCOM database (Pearson et al. 2008; http://calcomfish.ucsc.edu). The CALCOM database is the repository for commercial groundfish market sample data managed by the California Cooperative Groundfish Survey (CCGS). Since there were no commercial fisheries for common thresher sharks in Oregon and Washington prior to 1983, relying only on catch data from California for this early period is adequate for the assessment. The landings recorded in the CALCOM database were based on dressed weight, which were converted into round weights using the PacFIN conversion factor. The gear types in the CALCOM database (Net; Hook-and-Line; and Other) do not differentiate between USDGN and USSN fisheries. The seasonal proportions of catch for USDGN vs USSN fisheries during 1981-1985 were used to split the net catch for 1969-1980 into USDGN and USSN catch. The catch data from the hook-and-line and other gears were added to the USDGN (F1) and USDGNs2 (F2) fleets.

Some of the commercial landings for common thresher sharks were likely recorded as unspecified sharks (Pearson et al. 2008). A correction to the estimated removals by USA fisheries for this likely misrecording of species was performed by estimating the proportion of unspecified shark landings that was likely to be common thresher sharks. We assumed that the proportion of common thresher sharks in the unspecified shark landings was the same as that for the specified sharks, and added the estimated amount of common thresher sharks in the unspecified shark catch to the estimated removals of the USDGN (F1), USDGNs2 (F2), and USSN (F3) fleets. In addition, we estimated the proportion of common thresher sharks that were discarded at sea as dead fish from observer records of the USDGN and USSN fisheries and used that to expand the removals of USDGN, USDGNs2, and USSN fleets to include dead discards.

2.1.1.2 Mexico fisheries

Until recently, shark landings in Mexico were not reported by species. Instead, shark landings were divided into two groups, “Tiburon” and “Cazon”, based on length. Sharks larger than 150 cm TL were considered tiburon while sharks smaller than 150 cm TL were classified as cazon. Thresher sharks (or “zorro” in Spanish) are generally classified as tiburon. Since 2006, species-specific landings reports have been publicly available from the Mexican fisheries agency, Comision Nacional de Acuacultura y Pesca (CONAPESCA), through a website (http://www.conapesca.sagarpa.gob.mx/wb/cona/consulta_especifica_por_produccion) but all three species of thresher sharks are combined into a single category (Zorro).

For this assessment, the fishery removals for Mexican fisheries were therefore estimated from annual reports of state-specific aggregated shark (Tiburon) landings from the Instituto Nacional de Pesca (INAPESCA) that were available from 1976 through 2013. The southern extent of the distribution of common thresher sharks coincides approximately with the border between the Mexican states of Baja California and Baja California Sur, so catch data from only Baja California were used to estimate removals. Since common thresher sharks are only landed on the Pacific coast, the proportion of aggregated shark catch that comes from the Pacific coast of Baja California was estimated using statistics from the Mexican fisheries agency office in Ensenada, Mexico, and then used to estimate aggregated shark catches for the Pacific coast of Baja California.

Based on the work of Sosa-Nishizaki et al. (2002), Sosa-Nishizaki et al. (2008), and Cartamil et al. (2011a), we estimated the proportion of common thresher sharks in the aggregated shark catch of the Pacific coast of Baja California for specific periods since 1976. The estimated proportion of common thresher shark catch ranged from 0.06 in 1976 to a high of 0.2 in the mid-1980s, when the MXDGN fishery developed, before declining as the MXDGN fishery changed gradually to longline gear and was eventually prohibited. The estimated common thresher shark catch was then separated into monthly catch by the MXDGN, MXLL and MXART fisheries based on the work of Sosa-Nishizaki et al. (2002), Sosa-Nishizaki et al. (2008), and Cartamil et al. (2011a). The estimated monthly catch was then aggregated into seasonal removals by the MXDGNLL (F6), MXDGNLLs2 (F7), and MXART (F8) fleets for the assessment.

The estimated removals from 1976 – 2013 for each fleet were extrapolated to the 1969 – 1975 period and 2014 in order to match the 1969 – 2014 assessment period. The 2014 seasonal catch was assumed to be the average of the 2011 – 2013 seasonal catch. The 1969 – 1975 seasonal catch was assumed to be the average of the 1976 – 1978 seasonal catch.

2.1.2 Recreational removals

Estimated removals of common thresher sharks by USA private vessel recreational anglers from 1981 through 2014 were obtained from the Recreational Fisheries Information Network (RecFIN) (http://www.recfin.org), which is a recreational fisheries database maintained by the Pacific States Marine Fisheries Commission. The RecFIN removal estimates are based on angler surveys in California, Oregon, and Washington. From 1980 through 2003, the angler survey data were provided in "waves", which were bimonthly periods (i.e., Jan-Feb; Mar-Apr). Since the definition of seasons for this assessment were not consistent with these bimonthly periods, it was assumed that the removals within a bimonthly period were split equally between the two months in a single wave. Survey data from 2004 were provided on a monthly basis and did not require this assumption.

Estimates of common thresher shark removals by USA recreational anglers on CPFVs from 1969 through 2014 were obtained from the CPFV logbook database maintained by CDFG. The logbook data contained the daily species-specific catch of the CPFVs (Hill and Schneider 1999).

The seasonal removals by recreational anglers on private vessels and CPFVs were summed into the USREC (F4) and USRECs2 (F5) fleets. It should be noted that estimated removals for the USREC (F4) and USRECs2 (F5) fleets were in 1000s of fish rather than the metric tons for all other fleets.

2.1.3 Abundance indices

Indices of relative abundance were derived from logbook data of the USDGN and USSN fisheries using generalized linear models (GLMs). Details and diagnostics of the GLMs used to derive the abundance indices for the USDGN and USSN fisheries can be found in Appendices A and B respectively. A delta-lognormal approach (Lo et al. 1992) was taken to explicitly account for proportion of sets having zero versus non-zero catch. A binomial GLM was used to estimate the expected probability of non-zero catch for a given set and a lognormal GLM was used to estimate the expected catch for a given set with non-zero common thresher shark catch. The binomial and lognormal GLMs were independent and the explanatory variables used in each GLM were not necessarily the same, except for the year factor, which was present in every GLM. A stepwise model selection process using Akaike's Information Criteria (AIC) as the selection criteria was used. Uncertainty in each index was estimated by jack-knifing the data used to calculate the index. The abundance indices and corresponding uncertainty are shown in Table 2.3.

2.1.3.1 USA swordfish/shark drift gillnet fishery

The USDGN fishery is the most important fishery in this assessment, and primarily catches sub-adult and adult sharks. The abundance indices from this fishery are therefore expected to be the most important indices for this assessment.

Three indices representing different regulatory and operational periods were developed for the USDGN fishery: 1) 1982 – 1984 (S1); 2) 1992 – 2000 (S2); 3): 2001 – 2013 (S3). Changes in the regulations and fishery operations of this fishery have likely affected the catchability of this fishery (Urbisci et al. in review). The most important regulatory changes occurred in 1982, 1985, 1989, 1992, and 2001, when time-area closures were implemented or changed. For this assessment, we did not attempt to account for the effect of these time-area closures in our GLMs. Instead, we developed shorter time series within the periods when regulatory changes were likely less important. Logbook data for 2014 were also not available by the time that development of abundance indices was completed. An abundance index was not developed for the 1985 – 1991 period because of changing regulations and fishery operations. In addition, preliminary examination of the logbook data indicated that the CPUE rapidly increased and decreased several fold during this period, which indicated that changing regulations and fishing operations likely resulted in the exploitation of some local areas of high abundance.

Regulatory changes over the years have also affected the start of the fishing season. Therefore, only data from seasons 3 and 4 (i.e., Aug – Oct and Nov – Jan) were used for the abundance indices because fishing consistently occurred during these seasons. Three bimonthly periods within the six month period were used as factors in the GLMs to account for changes in thresher CPUE due to time of year.

The annual decile rank of swordfish catch of a given set was included in the GLMs to account for changes in the targeting of the fishery from pelagic sharks to swordfish. In the initial development of the fishery, the primary target of the fishery changed from pelagic sharks to swordfish because of higher market prices. However, the targeting switch was constrained by regulations restricting the total amount of monthly swordfish landings and requirements to land equal amounts of shark (Table 1.1). Even after regulations restricting swordfish catch were removed, USDGN vessels likely switched between swordfish and pelagic sharks depending on availability and market prices. The annual decile rank of swordfish catch was determined by ranking the swordfish catch from all sets within a given year, and then splitting the ranks into deciles (e.g., 0-10%, 10-20%).

Additional initial uncertainty was estimated and assigned to each USDGN index in addition to the data uncertainty estimated using a jackknife procedure. Since the USDGN indices represented the relative changes in the stock abundance of sub-adult and adult sharks, changes in the indices over time should be relatively smooth. Therefore, variability in the indices above and beyond that expected by the uncertainty in the data (i.e., estimated from the jackknife procedure) and a smoothly changing adult population, is largely due to variability in the catchability of fishery. In this assessment, we model the variability in catchability with additional uncertainty. The USDGN indices were fit to a loess curve and the coefficient of variation (CV) of the index relative to the loess curve was calculated. If this CV was greater than the mean CV calculated with the jackknife procedure, the additional uncertainty added was the difference in the CVs. Otherwise, no additional uncertainty was added unless the mean CV from the jackknife procedure was <0.2. In that case, additional uncertainty was added to the index until the mean CV was equal to 0.2. The estimated additional CVs for the three indices were: S1: 0.000; S2: 0.123; and S3: 0.392. These additional CVs were only included as initial inputs into the assessment model and were adjusted based on model fit to the indices (Section 3.5).

The S1 index (1982 – 1984) showed a general decline but being a short time series was not expected to be strongly influential (Table 2.3). The S2 index generally increased from 1992 through 2000 (Table 2.3). However, the S3 index exhibited a high variability in the index from year to year during 2001 through 2013 (Table 2.3). This was caused by the substantial reduction in the number of vessels in the USDGN fishery and consequently, a large reduction in effort.

2.1.3.2 USA set net fishery

The USSN fishery primarily catches age-0 common thresher sharks. The abundance indices from this fishery can therefore be considered as recruitment indices.

Two indices representing different regulatory and operational periods were developed for the USSN fishery: 1) 1986 – 1993 (S4); and 2) 1994 – 2014 (S5). In 1994, the California Marine Resources Protection Act prohibited all gillnets and trammel nets within 3 nm of the California mainland and 1 nm of the Channel Islands. Since age-0 common thresher sharks are known to be distributed close to shore (Cartamil et al. 2010), this regulatory change may have affected the catchability of the USSN fishery on common thresher sharks.

Logbook data from the USSN fishery were available from 1981 through 1985 but the data from this period were not used to develop abundance indices because the USSN data were mixed with the USDGN data and could not be easily separated. After 1985, when the USDGN fishery moved out of the 75 nm zone due to regulations, it became easier to separate the USSN fishery data from that of the USDGN fishery because the operations of the two fisheries became very different.

Unlike the USDGN indices, data from all four seasons were used in the USSN indices. In addition, it was not necessary to correct for the USSN fishery targeting swordfish instead of pelagic sharks because neither swordfish nor pelagic sharks are targets of the fishery.

No additional CVs were assigned to the USSN indices in addition to the data uncertainty estimated using a jackknife procedure. The USSN indices were not fit to a loess curve because we expected these recruitment indices to be highly variable unlike the USDGN indices. A minimum CV of 0.2 was assumed for all indices but the mean CVs from the jackknife procedure for both indices were >0.2.

2.1.4 Length composition data

In both the USA and Mexico, the sampling programs used to sample the length composition of the catch varied over time, depending on country and fishery. This resulted in changes in the types of length data collected (alternate versus fork lengths), availability of sex composition data, and sample sizes.

Common thresher sharks were predominantly landed as “trunks”, without heads and tails (this practice has recently been prohibited by USA regulations). This practice made it impossible for port samplers to measure the fork lengths of landed sharks. They therefore measured alternate lengths instead, which is the distance between the origins of the first and second dorsal fins (Childers and Halko 1994). However, onboard observers were able to measure the fork length of the sharks. It was therefore necessary to use a relationship between alternate and fork lengths to convert alternate lengths to fork lengths. Based on 3043 samples, Kohin et al. (pers, comm.) estimated the relationship as: $FL = 2.3627 \times AL + 16.82$ (Fig. 2.3), where FL and AL were the fork lengths and alternate lengths in cm, respectively. Using such a relationship resulted in aliasing of the length composition data. Preliminary analysis indicated that using 7 cm bins reduced aliasing to negligible levels for this relationship. We therefore used 7 cm bins for length composition data that were derived from measured alternate lengths. Smaller bins of 2 cm were used for data that were derived from measured fork lengths.

The genders of individual size samples were collected at the same time for some sampling programs. In general, port samples had very few and inconsistent number of length samples with associated sex information. However, onboard observers often collected sex information with their size samples.

A summary of the annual sampling effort by fleet, length type, and year used to generate the seasonal length frequency distributions are shown in Table 2.4. The initial input sample sizes (N_{input}) for the length composition data by season were the number of trips sampled, if available. For USA commercial fisheries, seasonal length frequency distributions with N_{input} <5 were not used in the assessment, which eliminated 5 out of 69, 7 out of 18, and 22 out of 42 seasons of length composition data available for the USDGN (F1), USDGNs2 (F2), and USSN (F3) fleets respectively. Mexico fisheries had much poorer sampling effort, so the minimal N_{input} required for seasonal length frequency distributions to be used in the assessment was 2, which eliminated 0 out of 3 seasons of length composition data available for the MXDGNLL (F6) fleet. The ranges of N_{input} for USA and Mexico commercial fisheries were 5 – 124 and 2 – 3 respectively.

2.1.4.1 USA fisheries

Length composition data from California port sampling and onboard observer programs were available for the USDGN and USSN fisheries. From 1981 through 1990, CDFG's port samplers collected length information from common thresher sharks landed by the USDGN and USSN fisheries (Childers and Halko 1994). These length samples were in alternate lengths rather than fork lengths, and were therefore converted to fork lengths for use in this assessment (Fig. 2.3). There was a negligible number of port samples with associated sex information but the sex composition data from these samples were not used in this assessment. In contrast, the onboard observer program (1990 – present) for these two fisheries recorded sex information on almost all of their length samples, which were measured as fork lengths. The sex composition data from the onboard observer program were incorporated into this assessment.

No length composition data were available for the USREC and miscellaneous fisheries. Based on anecdotal evidence, we assumed that the size of common thresher sharks caught by these fisheries were similar to the USDGN fishery.

2.1.4.2 Mexico fisheries

Length composition data from Mexico fisheries were much sparser than for the USA fisheries (Table 2.4). Scientists from Mexico sampled the lengths of common thresher sharks landed by the MXDGN and MXLL fisheries over several fishing trips during 2007 and 2008. These length composition data were in alternate lengths and were mostly unsexed. The MXART fishery was sampled over a period of time from 2006 till the present by scientists visiting fishing camps along the Baja California coast (Cartamil et al. 2011b). These length data were in fork lengths and were a mixture of sex and unsexed samples. However, the number of fishing trips from which the samples were taken was unknown.

Preliminary examination of the length composition data from the MXART fishery suggested that the size of sharks taken was different from the USSN fishery. Given the lack of sample size information, uncertainty in the sampling period, and the sparse data, we used a "super-year" approach when using the data in the assessment model. This approach combined all the length data from the fishery into a single length composition and assumed that was the average length composition for the entire time period.

Preliminary model runs fitting the length composition data from the MXGDNLL (F6) fleet resulted in highly uncertain and variable selectivity, and poor fits to the length composition data because of the sparse and variable length composition data. Examination of the data suggested that the overall size of common thresher sharks caught by the MXDGNLL (F6) fleet was similar to the USDGN (F1) fleet, which was likely due to their similar gear and fishing operations. Therefore, the length composition data from the MXDGNLL (F6) fleet were not fit in the base case model. Instead, the MXDGNLL (F6) and MXDGNLLs2 (F7) fleets were assumed to have the same selectivities as the USDGN (F1) and USDGNs2 (F2) fleets respectively.

2.1.5 Conditional age-at-length data

Sex-specific conditional age-at-length data from the age and growth study by Smith et al. (2008a) were used in this assessment. Most of the samples came from the USDGN (F1) fleet (N=183) and one sample came from the USSN (F3) fleet. These vertebral samples were aged by three independent readers at SWFSC using the techniques described in Cailliet et al. (1983).

Aging imprecision was estimated with the method described by Punt et al. (2008), using the R package “nwfscAgeingError” (Thorson et al. 2012). Each reader was assumed to be unbiased in turn, and the aging imprecision and bias (for the other two readers) were estimated. The best fitting model, based on AIC, suggested that the age readings by the lead reader (S. E. Smith) were unbiased and had a constant CV (0.176). The age readings and associated uncertainty were incorporated into the base case assessment model and all sensitivity runs with estimated growth.

2.2 Fishery-independent data

This assessment used fishery-independent data from a longline juvenile thresher shark survey conducted in nearshore waters of the SCB by NOAA Fisheries’ Southwest Fisheries Science Center (SWFSC). Overall catch and effort from the survey can be found in Table C.1 in Appendix C. The SWFSC juvenile thresher shark survey was conducted annually in September from 2006 through 2014. This survey was developed after an initial study on the common thresher shark nursery grounds (Smith 2005). The study indicated that longline gear in nearshore waters would be successful in catching age-0 and juvenile common thresher sharks.

The basic survey design consisted of 12 area blocks and a minimum of three longline sets were required for each block (Fig. C.1 in Appendix C). Each longline set consisted of a one mile long anchored monofilament longline with 100 hooks deployed from a small commercial longline vessel. The hooks were expected to fish approximately 6 – 8 m below the surface and were baited with primarily sardines but mackerels were sometimes used when sardines were not available. The longline sets were deployed in areas where bottom depth was <25 fathoms (~45 m). Sharks were tagged and released alive, if possible.

Several operational factors of this survey impacted how the survey data were utilized in this assessment. Most importantly, the location and timing of each set was determined by the captain of the vessel, within the constraints set by SWFSC scientists. The sets were in effect targeted at common thresher sharks and were somewhat similar to commercial longline sets. In addition, after the initial three sets within a block were completed and there was time available, the captain was free to set again in the same area. Therefore, the first three sets in an area were possibly used as learning sets, providing information on where it was more likely to encounter threshers in subsequent sets in the same block. Preliminary analysis of the CPUE indicated that sets after the first three sets do have a significant positive effect on encountering non-zero thresher catch.

Another important factor was that soak times of sets were inconsistent and varied substantially. When relatively large numbers of sharks were caught, soak times were sometimes cut to reduce shark mortality and possible hook saturation. Therefore, we included soak time as part of the fishing effort. Occasionally on some sets in the past, if a shark was seen hooked, the shark would be brought aboard and released, and the hook was then rebaited and put back into the water. This practice was considered inappropriate and has since been discontinued.

Other secondary factors likely impacting the CPUE of the survey were Marine Protected Areas (MPAs) and consumption of baits by sea lions. In 2012, several areas within survey blocks became unavailable to the survey due to MPAs being implemented. Preliminary analysis indicated that sets within those areas before they became MPAs had higher CPUEs. Sea lions would also occasionally consume the baits on the longlines, making the longlines less effective in catching fish. If the survey data indicated that baits were consumed by sea lions, the data from the set would be discarded before further analysis.

2.2.1 USA juvenile thresher shark survey index (USJUV0614)

A similar approach to the USDGN and USSN indices was used to derive an index of relative abundance for the juvenile thresher shark survey. Details and diagnostics of the GLMs used to derive the abundance index can be found in Appendix C. A delta-lognormal approach was taken, using binomial and lognormal GLMs (Lo et al. 1992). The effects of a set being in one of the first three sets within a block or within an MPA were accounted for by incorporating those factors as candidate factors in the GLMs. An AIC-based stepwise model selection process was used to select the final GLMs used to derive the index. Uncertainty in the index was estimated by jack-knifing the data.

Based on the size composition data, the juvenile thresher shark survey catches a mixture of age-0 and juvenile thresher sharks. This index should therefore be considered as a recruitment index. The estimated abundance index and uncertainty are shown in Table 2.3.

Additional CVs were not assigned to this index because the estimated CVs from the jackknife procedure were relatively high, with a mean CV of 0.485. The high CVs were due to the highly patchy distribution of juvenile thresher sharks and relatively low number of longline sets in the survey. In addition, we expect a recruitment index to have relatively high variability unlike the indices based on the USDGN fishery.

No obvious trends were observed in the estimated index because of the highly variable index and high estimated CVs. The large estimated CVs resulted in this index being uninformative in preliminary models. The juvenile thresher shark survey index was therefore not fit in the base case model, and was instead used in a sensitivity analysis (Section 6.1.4).

2.2.2 Length composition data

Common thresher sharks caught by the juvenile thresher shark survey were measured (fork length) and sexed. The length and sex composition data from the survey were fit in the base case model. The number of sets and fish used to generate the seasonal length frequency distributions are shown in Table 2.4. The initial input sample sizes (N_{input}) for the length composition data by season were the number of sets sampled.

2.3 Biological parameters

Several biological parameters used in this assessment were fixed at externally determined values, which were obtained from published sources.

2.3.1 Maximum age

Based on previous biological studies, the maximum age of this stock of common thresher sharks was assumed to be 25 years for both sexes (Smith et al. 2008a; Smith et al. 2008b). With a natural mortality of 0.179 y^{-1}, approximately 1% of a cohort was expected to reach the age-25+ plus group, without fishery removals. This was consistent with previous analyses of this common thresher shark stock (PFMC 2003; Smith et al. 2008b).

2.3.2 Natural mortality

The instantaneous rate of natural mortality (M) was assumed to be a constant 0.179 y^{-1} for both sexes of this common thresher shark stock. This M was estimated by Smith et al. (2008b), based on a maximum age of 25 years using the relationship: $\ln M = 1.44 - 0.982 \ln w$, where M was natural mortality and w was maximum age (Hoenig 1983). The natural mortality used in this assessment was consistent with previous analyses of this stock (PFMC 2003; Smith et al. 2008b). A sensitivity analysis was performed to examine model results with respect to alternative assumptions for M (Section 6.1.3.1)

2.3.3 Maturity and fecundity

The females of this common thresher shark stock were assumed to be 50% mature at age-5 and 100% mature at age-6+, based on Smith et al. (2008a). This was consistent with previous analyses of this stock (PFMC 2003; Smith et al. 2008b). However, recent work on the western North Atlantic stock of common thresher sharks suggested a median age of maturity of 12 years (Natanson and Gervelis 2013). A sensitivity analysis was performed to determine the effect of an age of 50% maturity of 12 years (Section 6.1.3.3).

Following the analyses of PFMC (2003) and Smith et al. (2008b), we assumed that this stock of common thresher sharks produced four pups per year and there was no change in fecundity with respect to female size or age. However, Natanson and Gervelis (2013) suggested that the western North Atlantic stock had at least a biennial reproductive cycle with litter sizes of 3.7 pups. A sensitivity analysis was performed to determine the effect of a biennial reproductive cycle by halving the fecundity to two pups per year (Section 6.1.3.3).

2.3.4 Weight-length relationship

The weight-length relationship used in this assessment followed the relationship estimated by Kohler et al (1995): $WT = 1.8821\times10^{-4}\ FL^{\,2.5188}$, where WT was the weight in kg and FL was the fork length in cm. This relationship was based on data from the western North Atlantic stock but visual examination of limited weight-length data suggested that this weight-length relationship was representative of this stock as well (S. Kohin, personal communication). Male and female sharks were assumed to have the same weight-length relationship.

3. Model description

The base case model used for this assessment is described below.

3.1 Modeling software platform

The assessment model was developed using the 3.24U version of the Stock Synthesis (SS) modeling platform (Methot and Wetzel 2013).

3.2 General model specifications

This assessment incorporated information from the entire distribution of common thresher sharks along the west coast of North America, from Baja California, Mexico to British Columbia, Canada. Based on currently available evidence, we assumed that this was a single, well-mixed stock (Section 1.1).

The start year of the base case model was 1969, which was the earliest year of reliable information on fishery removals, and the terminal year was 2014, which was the last year of available data. Each fishing year was divided into four seasons (1: Feb-Apr; 2: May-Jul; 3: Aug-Oct; and 4: Nov-Jan) (Section 2). The model was sex-specific due to differences in biology between genders, and the sex ratio at birth was assumed to be 1:1. The configuration and nomenclature of the eight fleets and six abundance indices in the base case model can be found in Table 2.1. Fishery removals were divided among 8 fleets (Section 2.1 and Table 2.2). Six indices of relative abundance were available for the model but only 5 were fit in the base case model (section 2.2). For convenience, abundance indices were inputted into the model as surveys and named accordingly (e.g., S1, S2). A summary of the data can be found in Fig. 2.1.

The length frequency distributions were based on fork lengths (cm) divided among 130 2-cm bins (40 – 300 cm) for measured fork lengths, and 38 7-cm bins for measured alternate lengths converted into fork lengths. However, length frequency distributions for the USSN fleet required a modification to this length bin structure. Preliminary models indicated that length compositions of age-0 fish from the USSN fleet were poorly fit in all preliminary model configurations and also tended to degrade the fit to other fleets with age-0 observations. Visual examination of the length compositions of the USSN fleet suggested that the quality of the length observations of age-0 sharks in this fleet was relatively poor compared to the length observations from the juvenile thresher survey. Given that most of the common thresher sharks (>95% in number) caught by the USSN fleet were age-0, the bins from 40 – 93 cm were aggregated into a single bin to approximate the age-0 size classes, and an age selectivity process was used to represent the selectivity of the USSN fleet. Doing so resulted in better fits to the data from this and other fleets. A sensitivity analysis was performed to illustrate the sensitivity of model results to this structural change coupled with a length selectivity process (Section 6.1.5.2).

3.3 Likelihood components

In the assessment model, likelihoods for the various data components were obtained by comparing the expected values from the model with the observations in the data based on 'goodness of fit' procedures for the appropriate likelihood distribution for the data component. The main likelihood components in the model included: 1) abundance indices (lognormal); 2) fleet and survey length frequency compositions (multinomial); and 3) conditional age-at-length data (multinomial).

3.4 Model parameterization

Four main types of parameters were in the assessment model: 1) life history; 2) stock-recruitment; 3) selectivity; and 4) initial conditions. These parameters were either fixed or estimated within the model. Reasonable bounds were specified for all parameters. Catchability was estimated for each index of abundance without any prior assumptions.

3.4.1 Life history

Except for growth, all other life history parameters were fixed in the model, including natural mortality, weight-length relationship, maturity-at-age, and fecundity. These fixed parameters were derived from data available or published literature (Section 2.3 and Fig. 3.1). Sensitivity of the model to the natural mortality, maturity-at-age, and fecundity parameters was analyzed (Section 6.1.3).

3.4.1.1 Growth

In this assessment, growth was estimated within the model, assuming that growth was sex-specific and time-invariant. Preliminary models using fixed growth parameters from a previous study on this stock (Smith et al. 2008a) (Section 1.1.4) had poor fits to the size compositions of age-0 fish from the USSN fishery and the USA juvenile thresher shark survey because age-0 fish in the data were substantially smaller and did not show the sex-specific differences in size expected by the fixed growth models. The age-0 size composition data could have been better fit if the selectivity of male and female age-0 sharks were very different but this was considered to be unlikely because the behavior of age-0 sharks did not appear to be sex-specific and the sex ratio of age-0 sharks caught in the USA juvenile thresher shark survey was approximately 1:1 in the same area. It was considered more likely that the estimated size at age-0 from the published studies were unrepresentative due to limited samples from age-0 fish. Estimating growth within the model substantially improved the fits to the size composition and conditional age-at-length data. Growth of male and female sharks were modeled separately because all previous studies on common thresher shark growth indicated that these sharks exhibited sex-specific growth (Cailliet et al. 1983; Smith et al. 2008a; Gervelis and Natanson 2013).

A von Bertalanffy growth function, as parameterized by Schnute (1981), was used to model the relationship between fork length (cm) and age:

$$L = L_\infty + (L_1 - L_\infty)e^{-K(A-A_1)}$$

where L_1 and L were the sizes associated with ages A_1 and A respectively, L_∞ was the asymptotic length, and K was the growth coefficient. The L_1, K, and L_∞ parameters were estimated for both male and female common thresher sharks and A_1 was set at 0.125. The coefficients of variation (CVs) of size-at-age for L_1 (CV_1) and L_∞ (CV_2) were fixed at 0.08 and 0.05 for both sexes, based on an estimate of the overall CV for age-0 fish caught by the USA juvenile thresher shark survey and estimated from preliminary model runs respectively.

Sensitivity of the model to the estimated growth model was analyzed by performing alternative model runs with growth parameters fixed at the values estimated by Smith et al. (2008a) (Section 6.1.3.2).

3.4.2 Stock-recruitment

Common thresher sharks produce only a few pups per litter, with relatively little variability in litter size between individuals. In addition, the pups are born at a relatively large size. This suggests that common thresher sharks have lower potential productivity than teleosts producing millions of eggs and there is likely a more direct connection between spawning abundance and recruitment than for teleosts.

Therefore, the stock-recruitment relationship was modeled using a relatively new functional form developed by Taylor et al. (2013) for low fecundity fish that explicitly modeled the pre-recruit survival during the period from pupping to recruitment at age-0. The survival of pre-recruit sharks, S_0, was calculated as,

$$S_0 = \frac{R_0}{B_0}$$

where R_0 was the recruitment at equilibrium without fishing, and B_0 was the equilibrium number of pups produced under unfished conditions, in number of animals, which was equal to the number of mature females multiplied by the number of pups per female (i.e., 4 in the base case model). Expected recruitment, based on the number of pups produced, for each year in the time series was then calculated as,

$$R_y = S_y B_y$$

where B_y was the spawning population in year y, and S_y is the pre-recruitment survival given by,

$$S_y = \exp\left[-z_0 + (z_0 - z_{min})\left(1 - \left(\frac{B_y}{B_0}\right)^{\beta}\right)\right]$$

where z_0 was the pre-recruitment mortality rate at equilibrium calculated as $-\log(S_0)$; z_{min} was the limit of the pre-recruitment mortality as depletion approaches 0 calculated as $z_0(1 - z_{frac})$, and z_{frac} represented the reduction in mortality as a fraction of z_0 (z_{frac} therefore ranged from 0 to

1); and β was the shape parameter of the density dependence between the spawning population and pre-recruitment survival.

The steepness, h, of the spawner-recruit curve (i.e., expected recruitment relative to R_0 at a spawning depletion of 0.2) can be derived from the parameters using,

$$h = 0.2 \exp\left[z_0 z_{frac}(1 - 0.2^{\beta})\right]$$

A suite of preliminary simulations, with model structures consistent with this assessment, were performed to examine if the β and/or z_{frac} parameters were estimable given the model structure and available data. Results from the simulations indicated that the available data were likely to be informative on the β parameter but not the z_{frac} parameter. Therefore, based on these simulation results, we fixed z_{frac} in the middle of a reasonable range for the base case model (base case: 0.6; range: 0.3 – 0.9) and estimated β. Sensitivity analyses were performed to evaluate the sensitivity of the model to the range of z_{frac} (Section 6.1.2.1). In addition, we also conducted sensitivity analyses using a Beverton-Holt stock-recruitment relationship with similar steepness to the low fecundity stock-recruitment relationship (Section 6.1.2.2).

Annual deviations in recruitment were modeled by replacing the B_y with,

$$B_y \exp\left[-0.5 b_y \sigma_R^2 + \tilde{R}_y\right], \tilde{R}_y \sim N(0, \sigma_R^2)$$

where b_y was the bias adjustment fraction applied for year y, σ_R was the standard deviation of the recruitment deviations in log space, and $\tilde{R}_y$ was the lognormal recruitment deviation for year y. The bias adjustment factor ensured that estimated recruitment during even ‘data poor’ eras, when the estimated $\tilde{R}_y$ was near 0, was unbiased (Methot and Taylor 2011). The bias adjustments for the base case and sensitivity analysis models were performed by estimating the expected bias adjustments using the R package ‘r4ss’ (v1.23.5) and then re-running the model again with the new bias adjustments. This bias adjustment procedure was performed once or twice depending on whether the estimated and expected bias adjustments were well matched after a single pass.

In this assessment, σ_R was assumed to be 0.5, which was consistent with the expected variability. A sensitivity analysis was conducted assuming a lower σ_R of 0.3 (Section 6.1.2.3).

3.4.3 Selectivity

The assessment model had a sex-specific structure, with sex-specific growth curves. However, we assumed that male and female common thresher sharks have identical selectivity for each fleet because the size composition data were adequately fit with this assumption, sex-specific size composition data were not available prior to 1990, and there was no available information that suggested selectivity differed by sex.

The USSN fleet (F3) was assumed to have an age-based selectivity because preliminary models using size-based selectivity fit the size composition data poorly and degraded the fit of other fleets with age-0 observations (Section 3.2). Using an age selectivity process together with a size bin structure that approximately aggregated age-0 observations resulted in better fits to the data. The selectivity of each age class from age-0 through age-2 was freely estimated, and the selectivity of ages >2 was assumed to be negligible for this fleet. A sensitivity analysis was performed to examine the sensitivity of model results to using size selectivity for this fleet rather than age selectivity (Section 6.1.5.2).

All other fleets were assumed to have size-based selectivity processes. Size selectivities were estimated for four fleets with size composition data (F1, F2, F8, and S6) and the size selectivities of other fleets were mirrored to one of these fleets (Table 3.1). The MXDGNLL (F6) fleet had several size composition observations in 2007 – 2008 (Table 2.4) but preliminary models indicated that the low sample sizes and variability of these observations resulted in the model poorly fitting these observations. Given that the size of common thresher sharks caught by this fleet was similar to the USDGN fleets (F1 and F2), we assumed that their size selectivities were also similar. Visual examination of the expected and observed size composition of the removals suggested that this assumption was adequate. A sensitivity analysis was performed that fit to the size observations from the MXDGNLL (F6) fleet (Section 6.1.5.3).

The selectivity curves for the USDGN (F1) and MXART (F8) fleets, and the USJUV0614 (S6) index were assumed to be dome-shaped and parameterized as double-normal curves (Table 3.1). Each double normal selectivity curve had six parameters: 1) peak, the initial length at which the fish is fully selected; 2) width of the plateau at the top; 3) width of the ascending limb of the curve; 4) width of the descending limb of the curve; 5) selectivity of the first size bin; and 6) selectivity of the last size bin. The parameters for peak, width of ascending limb, and width of descending limb were estimated for all three double-normal curves. In addition, the selectivity of the first size bin was estimated for the USDGN (F1) fleet but assumed to be controlled by the width of the ascending limb for the other two fleets and therefore not estimated. The selectivity of the final size bin was assumed to be controlled by the width of the descending limb and therefore not estimated for all three selectivity curves. The width of the plateau was assumed to be negligible and fixed at a very small value for all three selectivity curves because preliminary models indicated that this parameter was always estimated to be a very small value and at the lower bound for all three curves.

The size selectivity curves of the USDGNs2 (F2) fleet were parameterized as cubic splines with four knots because of bimodal size composition data. Preliminary models indicated that cubic splines with four knots at 75, 125, 175, and 225 cm allowed for flexible selectivity curves that adequately fit the size composition data. Sensitivity analysis on the location of the final knot was performed because that affected the selectivity at the final size bin, which can influence the estimated scale of the population (Section 6.1.5.4).

Selectivities of the USDGN (F1), USDGNs2 (F2), and USSN (F3) fleets were allowed to vary through time. The selectivities of these fleets were likely affected by major regulatory changes

(Table 1.1), which forced the fleets to change their fishery operations. Therefore, the selectivities of these fleets were grouped into blocks of time when their regulations and fishery operations were relatively consistent (Table 3.1). A sensitivity analysis was performed to examine the effect of alternative time blocks of selectivity (Section 6.1.5.1).

3.4.4 Catchability

Catchability, q, was estimated assuming that the abundance indices were proportional to vulnerable biomass with a scaling factor of q. It was assumed that q was constant over time for each index.

3.4.5 Initial conditions

In this assessment, we started the main population dynamics of the model in 1969, which was prior to the start of targeted commercial fishing in 1977 – 1978. Although there was some low level of exploitation of this stock prior to 1969, the level of exploitation was substantially lower than during the period of targeted fishing. It was therefore assumed that the population was relatively close to equilibrium in a near unfished state. The level of pre-1969 equilibrium catch was assumed to be the average of 1969 – 1971, and grouped into three fleets based on the approximate size and unit of catch: 1) the USDGN (F1 and F2) and MXDGNLL (F6 and F7) fleets for all seasons; 2) USREC (F4 and F5) for all fleets; and 3) the USSN (F3) and MXART (F8) fleets. The initial fishing mortality rates that remove these equilibrium catches were estimated to allow the model to start at an appropriate depletion level, albeit near an unfished condition. No early recruitment deviations (i.e. recruitment deviations prior to 1969) were estimated because the earliest size composition and abundance index observations were from 1981 and 1982 respectively, and the recruitment deviations during the period from 1969 to 1980 acted like early recruitment deviations, which allowed the model to develop a non-equilibrium age structure when the main observations started. A sensitivity run was used to examine the effect of starting the model in an unfished condition (Section 6.1.1.2).

3.5 Data weighting

Statistical stock assessment models fit a variety of data components, including abundance indices and size composition data. The results of these models can depend substantially on the relative weighting between different data components (Francis 2011). In this assessment, we use the method proposed by Francis (2011) (Method TA1.8) to weight the size composition data, using the SSMethod.TA1.8 function in the ‘r4ss’ package (v1.23.5). All estimated Francis weights of the size composition for all fleets were >1, which suggested that the size composition data did not have to be down-weighted. A R_0 profile of the data components (Lee et al. 2015) also suggested that the size composition data were relatively consistent with abundance indices with respect to estimated population scale (Section 4.4). Visual examination of the residual patterns of the size composition data suggested that the size composition data were relatively well fit and the scale of the Pearson’s residuals for each data component were consistent with the statistical assumptions (i.e., approximately 95% of the residuals were within ±2 standard deviations) except for the 2 cm bin data for the USDGN (F1) and USSN (F3) fleets. The larger than expected residuals for these two data components were due to large spikes in single bins, which were primarily attributed to noisy data and small sample sizes. Therefore, no adjustments were made to the input sample size (N_{input}) for the size composition data for all fleets.

Sensitivity analyses were performed where the variance adjustment factors for N_{input} followed the estimated Francis weights and were allowed to exceed 1.0; and where the N_{input} were down-weighted in turn using likelihood component weighting factors (i.e., lambda factors) of 0.2 (Section 6.1.4).

A similar data weighting process was performed for the conditional age-at-length data. Estimated Francis weights of the conditional age-at-length data using the SSMethod.Cond.TA1.8 function in the 'r4ss' package were >1, which indicated that the conditional age-at-length data did not have to be down-weighted. However, preliminary R_0 profiles suggested that the conditional age-at-length data were inconsistent with the abundance indices in terms of estimated population scale. We decided to down-weight the influence of the conditional age-at-length data because the data were intended to provide information on the growth of the fish but not to influence estimates of population scale, which was better represented by abundance indices. In the base case model, the contribution of the overall likelihood by the conditional age-at-length component was down-weighted by a lambda weighting factor of 0.2.

Input variances of the abundance indices were adjusted to make them consistent with the statistical assumptions of the model. The initial input coefficients of variance (CV_{input}) of the abundance indices were the sum of the estimated observation error and variance adjustment factors based on the estimated additional process errors (USDGN indices only) (Section 2.1.3). After the initial model was run, the estimated root-mean-square errors of the model fit to the abundance indices were used to adjust the variance adjustment factors to allow the total expected errors to be consistent with the estimated errors. The minimum value allowed for variance adjustment factors was 0.0, in order to limit the minimum expected error to the observation errors estimated by jack-knifing the data.

4. Model selection and evaluation

4.1 Alternative model configurations

A large number of alternative model configurations were explored to develop the base case model, which provided a realistic but parsimonious description of common thresher shark population dynamics based on the best available scientific information. The alternative models were evaluated on overall model fit and convergence criteria, as well as consideration of whether model assumptions, structural choices, estimated parameters, and outputs were reasonable and consistent with available information for the stock. The base case model reflected the best aspects of these exploratory models. Overall, the base case model fit the observed data well, with plausible model processes and estimated parameters were within reasonable bounds.

Several models that describe alternative states of nature are described in the sensitivity analyses section (Section 6.1). These include alternative assumptions on growth, reproductive biology, natural mortality, stock-recruitment relationship, total removals, data weighting, and selectivity.

4.2 Model convergence

Convergence of the base case model was indicated by all of the tests that were conducted. The base case model had a maximum gradient component that was very close to zero (2.20974E-5), a positive definite Hessian matrix, and all estimated parameters were within reasonable bounds. We also explored the likelihood surface of the model using 50 runs with different phasing and initial values. Total negative log-likelihood from the model run using the phasing and initial parameters from the base case model was the lowest (i.e., best) among these runs, and 33 out of 50 runs also obtained the same total negative log-likelihood (Fig. 4.1). In addition, the estimated virgin recruitment in log-scale [ln(R_0)] was similar from runs with similar likelihoods to the base case model (Fig. 4.1).

4.3 Model fit

The fit of the base case model to observations were determined by examining the residuals of the abundance indices, size compositions, and conditional age-at-length data.

4.3.1 Fit to abundance indices

The base case model was able to adequately capture the trends indicated by the sub-adult/adult (S1, S2, and S3) and recruitment (S4 and S5) abundance indices that were fit (Fig. 4.2). Importantly, the base case model results were consistent with the population decline observed by the S1 index during 1982 – 1984, and the increasing population trend observed by the S2 index during 1992 – 2000. However, we note that the observed trends during these two periods were steeper than expected. The lack of contrast and large uncertainties of the observations for S3 during 2001 – 2013 made it difficult to ascertain how well the base case model matched the observed population trends during that period. The base case model captured the trends in recruitment observed by the S4 and S5 indices.

Overall, the model fits to the sub-adult/adult indices (S1, S2, and S3) were poorer than the recruitment indices (S4 and S5) but were considered to be adequately representative of abundance trends and consistent with model input CVs. The RMSEs of the S1, S2, and S3 indices were 0.157, 0.391, and 0.545 respectively while the RMSEs of the S4 and S5 indices were 0.176 and 0.178 (Table 4.1). The RMSEs of the S1, S4, and S5 indices were smaller than their input CVs based on observation errors while the RMSEs of the S2 and S3 indices were approximately equivalent to the sum of their input CVs and variance adjustments after tuning.

4.3.2 Fit to size compositions

Base case model fits to the size composition data were generally good. Overall, the model predicted size compositions that matched observations well (Fig. 4.3 – 4.5). Examination of the input sample size (input N) and model estimated effective sample size (*effN*) also showed reasonably good model fits (Table 4.2). A higher *effN* indicates better model fit, with a mean *effN* > 30 indicating good model fit. In addition, ratios of the harmonic mean of the *effN* to mean input N were all ≥1, which indicated that the base case input N did not assume less error than was evident in the model fits.

Pearson residuals of the model fit to the size composition data did not reveal substantial patterns in the residuals (Fig. 4.6 – 4.7). In addition, the scale of the residuals were generally small, with most lying within ±2 standard deviations. Exceptions to this occurred in the USDGN (F1) and USSN (F3) fleets when 2-cm bins were used because of several large spikes in the size compositions, which could not be fit with reasonable model processes.

4.3.1 Fit to conditional age-at-lengths

Base case model fits to the conditional age-at-length data were generally good. Overall, the model predictions matched observations well although some large fish appeared to have been aged at unreasonably young ages (Fig. 4.8). The ratios of the harmonic mean of the *effN* to mean input N were all ≥1, which indicated that the base case input N did not assume less error than was evident in the model fits (Table 4.3).

4.4 Retrospective analysis

Retrospective analysis did not reveal any pattern in the estimates of female spawning abundance and fishing intensity (1-SPR) with successive elimination of up to five years of terminal year data (Fig. 4.9).

4.4 Likelihood profiles on virgin recruitment (R_0 profile)

Results of the likelihood profiling on virgin recruitment, R_0, for the abundance indices and size composition data components of the model are shown in Fig. 4.10. Changes in the likelihood of each data component are a measure of how informative that data component is to the overall estimated population scale and what that scale is. Ideally, catch and abundance indices should be the primary sources of information on the population scale in a model (Lee et al. 2015).

In the base case model, the abundance indices appeared to be the primary sources of information on R_0. The USDGN9200 (S2) and USSN9414 (S5) indices had the largest influences on R_0 but the other three indices had negligible information on R_0. This was because both S2 and S5 indices had good contrast coupled with moderate amounts of observations and/or uncertainty. The maximum likelihood estimates of R_0 for the S2 and S5 indices were also relatively consistent with each other and the overall R_0 estimate. In comparison, the USDGN8284 (S1), USDGN0113 (S3), and USSN8593 (S4) indices had some combination of small number of observations, large uncertainties and/or limited contrast.

The size composition data also influenced the R_0 estimate but appeared to be relatively consistent with the information from the abundance indices. The USDGN (F1) fleet had the largest influence among all the fleets with size compositions, which was expected because the F1 fleet had the largest number of size composition observations. None of the size composition data from other fleets had major influences on R_0. Given that the R_0 profiles of the size composition data were consistent with the abundance indices, we considered the scale of the population to be adequately estimated by the base case model.

4.5 Age-structured production model analysis

Following the proposal by Maunder and Piner (2015), the base case model was modified into an age-structured production model to identify if the catch and sub-adult/adult abundance indices were consistent with the estimated scale and trends in the population. Maunder and Piner (2015) stated that "When catch does explain indices with good contrast (e.g., declining and increasing trends), it suggests that a production function is apparent in the data, therefore providing evidence that the index is a reasonable proxy of stock trend". In this assessment, the base case model was modified by fixing the stock-recruitment relationship, sex-specific growth curves, and selectivities of all fleets to those estimated in the base case model, not estimating annual recruitment deviates so that recruitment follows the stock recruitment curve, and not fitting to the size composition and conditional age-at-length data.

The age-structured production model had similar scale and populations trends to the base case model (Fig. 4.11). Model fits to the sub-adult/adult abundance indices (S1, S2, and S3) were also similar to the base case model (Fig. 4.11), which suggested that the sub-adult/adult indices were reasonable proxies of stock trend and the productivity of the stock was estimated reasonably well.

5. Model results

5.1 Model parameter estimates

The estimated or fixed values of the explicit parameters used in the base case model are shown in Table 5.1. All estimated parameters except initial fishing mortality were estimated within reasonable bounds. The initial fishing mortalities were estimated very close to the lower bounds (i.e., very close to 0), which is reasonable because the stock was close to being in an unfished condition at the start of the model.

5.1.1 Growth

Growth parameters of female and male common thresher sharks were estimated within the model and were consistent with what we know of the species (Fig. 5.1). Female sharks were slightly larger than male sharks for each age. However, the size difference between sexes appeared to be smaller than previously estimated. In addition, the size at age-0 appeared to be smaller than previously estimated.

5.1.2 Selectivity

Estimated selectivity curves are shown in Figures 5.2 – 5.4. Selectivity parameters were well estimated and selectivity curves were consistent with the known fishery operations of the fleets.

Higher selectivities for smaller fish were estimated for the USSN (F3), and MXART (F8) fleets, and the USJUV0614 survey (S6), which catch predominantly small, juvenile common thresher sharks. The peak parameters for F8 and S6 were <85 cm and selectivity of age-0 sharks for F3 was substantially higher than age-1 and 2 sharks (Table 5.1). In contrast, the selectivity curves of the USDGN (F1) and USDGNs2 (F2) fleets, which catch primarily sub-adult and adult sharks, had peak selectivities closer to 150 cm. A clear bimodal selectivity pattern was estimated for the USDGNs2 (F2) fleet during 1985 – 1988 because a large number of large sharks >200 cm were caught during this period (Fig. 5.5), which may have been due to time-area closures affecting fishing operations.

5.1.3 Catchability

The catchability coefficient (*q*) was solved analytically in the base case model as a single value for each index (Table 4.1). Catchability was allowed to vary through time by separating the abundance index from a single fishery into multiple time series based on an examination of the fishery operations of the fishery.

5.1.4 Catch-at-age

Juvenile and sub-adult common thresher sharks (ages-0 to 4) formed the largest component of the catch (Fig. 5.6), even during the peak of the USDGN fishery in 1982. This is because the selectivity of all fleets select for a substantial proportion of juvenile and sub-adult sharks.

5.1.5 Sex ratio

The sex ratio (male/female) estimated in the base case model was close to 1:1 because the estimated female growth curve was similar to the male growth curve, and selectivity was assumed to be non sex-specific (Fig. 5.7).

5.2 Stock assessment results

5.2.1 Reproductive capacity and output

In this assessment, the reproductive capacity of the population was calculated as the number of mature female sharks (i.e., spawning abundance) rather than spawning biomass, because the size of mature female sharks did not appear to affect the number of pups produced (i.e., larger female sharks did not produce more pups). The reproductive output of the stock (i.e., the number of pups produced by the stock) was calculated using four pups produced per year per mature female shark.

In the base case model, the estimated number of mature female common thresher sharks under unfished conditions was 88,200 sharks (95% CI: 69,500 – 107,000 sharks) with a reproductive output of 352,900 pups (95% CI: 278,000 – 427,800 pups) (Table 5.2 and Fig. 5.8). Prior to the start of targeted commercial fishing in 1977 – 1978, the estimated reproductive capacity was 93,000 mature female sharks (95% CI: 74,200 – 111,800 sharks) in the early 1970s. The start of targeted commercial fishing in 1977 – 1978 was quickly followed by a large increase in fishery removals, peaking in the early 1980s (Fig. 2.2). These relatively large removals resulted in the number of mature female sharks declining quickly to approximately 35,200 sharks (95% CI: 21,300 – 49,100 sharks) in 1985. Over the next decade, the number of mature female sharks continued to decline but at a substantially slower rate, likely due to the management of the USDGN fishery during this period. The historical low estimate occurred in 1995, with 26,800 mature female sharks (95% CI: 15,000 – 38,600 sharks). After 1995, the reproductive capacity gradually increased over the past two decades. In 2014, the terminal year of the assessment model, the estimated number of mature female sharks reached 83,300 sharks (95% CI: 49,500 – 117,100 sharks) with a reproductive output of 333,100 pups (95% CI: 198,000 – 468,300 pups) (Table 5.2).

Depletion of the stock was estimated as the number of mature females in the second quarter (S) for a specific year divided by the number of mature females under unfished conditions (S_0) because the reproductive output of the stock (i.e., number of pups produced) was dependent on the number of mature females and not on the weight of the female sharks. Therefore, the estimated depletion followed the same trajectory as the number of mature female sharks, albeit scaled to S_0 (Table 5.2 and Fig. 5.8). The total (age-1+) and mature female biomass were both less important than the number of mature females as an indicator of the stock, but both also showed similar trends (Table 5.2 and Fig. 5.8).

5.2.2 Recruitment

The estimated recruitment and stock-recruitment relationship were generally consistent with the biology of the stock and assumptions in the base case model. Conditional on a fixed z_{frac} of 0.6, the base case model estimated a shape parameter, β, of 3.059, which indicated that the stock-recruitment relationship had a moderate curvature (Table 5.1 and Fig. 5.9). Unfished recruitment was estimated to be 77,100 sharks ($\log(R_0) = 4.345$) (Table 5.1). The estimated recruitment deviations from the expected spawner-recruit curve appeared to be relatively well estimated and consistent with the expected distribution of recruitment deviations ($\sigma_R = 0.5$), but there appeared to be a small amount of autocorrelation in the time series that was unaccounted for in the base case model (Fig. 5.9). The change in recruitment bias was consistent with expectations and accounted for in the base case model (Fig. 5.9).

The estimated recruitment fluctuated substantially during the assessment period (1969 – 2014), ranging from a low of 40,700 sharks (95% CI: 23,300 – 58,100 fish) in 1989 to a high of 150,500 sharks (95% CI: 86,400 – 214,600 fish) in 2006 (Table 5.2 and Fig. 5.9). Overall average recruitment during the assessment period was approximately 73,700 sharks but there appeared to be a period of relatively low recruitment from 1985 – 1995, with average recruitment at 56,700 sharks. In contrast, a more recent period from 2006 – 2012 had substantially higher recruitment, averaging approximately 115,600 sharks.

5.2.3 Fishing mortality

Fishing mortality-at-age (F-at-age) was estimated for female and male common thresher sharks in the base case model (Fig. 5.10). The fishing mortality was highest on the sub-adult and adult sharks during the peak of the swordfish/shark drift gillnet fishery. In recent years, the declining catch and effort from this and other fisheries have resulted in substantially lower fishing mortality for all ages. There did not appear to be substantial differences in the fishing mortality between female and male sharks.

Female spawning potential ratio (SPR) was used to describe the fishing intensity on the stock. The SPR of a population is the ratio of spawning output per recruit under fishing to the spawning output per recruit under unfished conditions (Goodyear 1993). Therefore, 1-SPR is the reduction in the spawning output per recruit due to fishing and can be used to describe fishing intensity on a fish stock. The fishing intensity (1-SPR) on this common thresher shark stock ranged from a low of 0.067 in 1971, prior to the start of targeted commercial fishing, to a high of 0.831 in 1982 during the peak of the swordfish/shark drift gillnet fishery (Table 5.2 and Fig. 5.11).

6. Model uncertainty

The assessment explicitly estimated the model uncertainty due to uncertainty in parameter estimates. These uncertainties were reported as confidence intervals for key parameters and management quantities (Table 6.1). These confidence intervals captured the uncertainty in the model fits to the data sources in the assessment but did not include uncertainty in model specification and fixed parameters. We used a suite of sensitivity runs to explore the uncertainty associated with alternative model specification and examine the sensitivity of important model outputs to different model assumptions.

6.1 Sensitivity analyses

A large number of alternative model specifications were used to examine the sensitivity of model results to different model assumptions. Only the most important ones are reported here. Summarized results of these sensitivity runs can be found in Table 6.1 and Figs. 6.1 – 6.17. Unless otherwise stated, input variances of abundance indices in the sensitivity runs were adjusted to make them consistent with the statistical assumptions of the model, and recruitment bias adjustments were performed. In addition, all sensitivity runs except for the run described in Section 6.1.4.2, used a data weighting approach that was consistent with the base case model. Essentially, a maximum weighting factor of 1 for all size composition data was used for the sensitivity runs and since estimated Francis weights of size composition data were all >1, all size composition weighting factors were set to 1 unless otherwise specified.

6.1.1 Alternative assumptions about fishery removals

6.1.1.1 High and low catch

Commercial landings of common thresher sharks by the USA West Coast commercial fisheries were relatively well known due to the CALCOM and PacFIN databases. However, there was uncertainty associated with potential misidentification of common thresher sharks as unspecified sharks (Pearson et al. 2008) or other less common species of thresher sharks (i.e., pelagic and bigeye thresher sharks). The commercial landings from Mexico fisheries were less well known but we assumed that the uncertainty associated with our estimates of removals by the Mexico drift gillnet, longline, and artisanal fisheries were approximately ±30%.

To explore the sensitivity of model output to the uncertainty in fishery removals, we developed two alternative fishery removal time series: 1) high catch, and 2) low catch. The high catch scenario was based on including all landings of unspecified sharks, and pelagic and bigeye thresher sharks by the USA West Coast commercial fisheries as landings of common thresher sharks, and setting the Mexico commercial landings to base case +30%. Conversely, the low catch scenario was based on excluding all landings of unspecified sharks, and pelagic and bigeye thresher sharks by the USA West Coast commercial fisheries, and setting the Mexico commercial landings to base case -30%. The dead discard rates for USA commercial fisheries were assumed to be the same for the base case model and both alternative catch scenarios. The removals by the USA recreational fishery were relatively minor compared to the commercial fisheries and were not adjusted for either catch scenario. However, the initial equilibrium catches for the high and low catch scenarios were adjusted accordingly to be the average of 1969 – 1971 for their respective scenario.

Although the absolute scale of the estimated unfished and current reproductive output changed, the trends in the estimated depletion levels as well as the status of the stock relative to reference points differed only slightly (Table 6.1 and Fig. 6.1).

6.1.1.2 Unfished initial conditions

In the base case model, we assumed that the level of pre-1969 equilibrium catch was the average of 1969 – 1971, and the initial fishing mortality was estimated from that initial catch. However, the population could have been in an unfished state at the start of the model. Therefore, we explored the effect of starting the model in an unfished state by fixing the initial fishing mortality to zero for all fleets and not fitting to the initial catch. The absolute scale of the unfished reproductive output was slightly lower if the model was started under unfished conditions but the trends in reproductive capacity were highly similar (Table 6.1 and Fig. 6.2).

6.1.2 Alternative assumptions about stock-recruitment

6.1.2.1 Alternative z_{frac} values

A z_{frac} value of 0.6 was assumed for the base case model. However, it was unclear what z_{frac} values were appropriate for common thresher sharks, and preliminary models and simulations suggested that z_{frac} could not be reliably estimated with the available data. A large range of z_{frac} values (0.3 – 0.9) were used in sensitivity runs to explore the effects of assumed z_{frac} values on model results. The shape parameter, β, of the stock-recruitment relationship was estimated for these sensitivity runs.

Assuming different z_{frac} resulted in relatively large changes to the estimated management quantities. Both estimated unfished recruitment and β became lower as z_{frac} was changed from 0.3 to 0.9 (Fig. 6.3). As a result, pup survival curves were flatter and lower at low z_{frac} values. At low z_{frac} values, the expected recruitments were generally higher but with recruitment maxima occurring at higher stock levels. The general trends in the estimated number of mature female sharks, spawning depletion, and fishing intensity were similar for all z_{frac} values but there were substantial differences in scale, especially at low z_{frac} values (Fig. 6.4). For example, the estimated number of mature females in the terminal year, 2014, was substantially higher at a z_{frac} of 0.3 (202,100 sharks) than for the base case (z_{frac} = 0.6; 83,300 sharks) and at a z_{frac} of 0.9 (64,100 sharks) (Table 6.1). The estimated MSY had a bowl-shaped response to the range of z_{frac} used, with the MSY at a minimum for the base case model (z_{frac} = 0.6) (Table 6.1).

6.1.2.2 Beverton-Holt stock-recruitment

The base case model used the relatively new stock-recruitment relationship developed by Taylor et al. (2013) for low fecundity fish like common thresher sharks (Section 3.4.2). However, common thresher sharks may instead have a Beverton-Holt stock-recruitment relationship. Therefore, we explored the effect of using a Beverton-Holt stock-recruitment relationship at several levels of steepness (h): 1) h = 0.495 (equivalent to steepness in base case model; Section 3.4.2); 2) h = 0.4; 3) h = 0.6; and 4) estimated h.

The use of Beverton-Holt stock-recruitment relationships resulted in similar trends in the estimated number of mature females, recruitment, depletion, and fishing intensity (Fig. 6.5). However, the recovery of the stock was slower when Beverton-Holt stock-recruitment relationships were used, resulting in lower S_{2014}/S_0 ratios (Table 6.1 and Fig. 6.5).

6.1.2.3 Recruitment variability (sigma-R)

The expected recruitment variability in the base case model was set at a moderate level (σ_R = 0.5) that was consistent with estimated recruitment deviates for the base case model. The recruitment variability for sharks born at a moderately large size like common thresher sharks could conceivably be smaller than a σ_R of 0.5. The effects of using a σ_R of 0.3 were examined.

As expected, the estimated recruitment was slightly less variable when a σ_R of 0.3 was used, with lower recruitment since 2000 (Fig. 6.6). However, the trends in the estimated number of mature females, depletion, and fishing intensity were highly similar. The estimated recruitment deviates when using a σ_R of 0.3 were less variable than the base case model but many estimated deviates approached 0.5, suggesting that the base case model parameterization was likely more consistent with the data.

6.1.3 Alternative assumptions on life history

6.1.3.1 Alternative natural mortality

In the base case model, we assumed an instantaneous rate of natural mortality of 0.179 y^{-1} based on a maximum age of 25 years and Hoenig's relationship between maximum age and natural mortality (Hoenig 1983). Given that natural mortality was a highly uncertain parameter, we examined the effect of three alternative rates of natural mortality: 1) 50% of base case; 2) 75% of base case, and 3) 125% of base case. A fourth sensitivity run at 150% of base case was performed but the model did not converge and was therefore discarded.

The trends of estimated number of mature females, spawning depletion, and fishing intensity were relatively similar for all levels of natural mortality but differed in the estimated scale, especially for estimated fishing intensity (Table 6.1 and Fig. 6.7). As expected, the estimated scale of the population increased with increasing natural mortality, while the estimated fishing intensity decreased.

6.1.3.2 Alternative growth parameterization

Sex-specific growth was estimated in the base case model but growth of this stock was previously estimated by Smith et al. (2008a). In this sensitivity run, we fixed the growth of male and female sharks to the Smith et al. (2008a) estimates and did not fit to the conditional age-at-length data. The estimated number of mature female sharks, spawning depletion, and fishing intensity of the sensitivity run were highly similar to the base case model (Table 6.1 and Fig. 6.8). However, the model fit of the size compositions of age-0 female sharks caught by the USA juvenile thresher shark survey (S6) was substantially better in the base case model than the sensitivity run (Fig. 6.8).

6.1.3.3 Alternative assumptions on maturity and fecundity

The base case model used biological parameters from Smith et al. (2008a, b) because those studies were based on the same population of common thresher sharks as this assessment. However, a recent study on the reproductive biology of the western North Atlantic stock of common thresher sharks (Natanson and Gervelis 2013) demonstrated a much higher median age of maturity for female sharks (12 vs 5 years) and longer reproductive cycle (biennial or triennial vs annual cycle). Therefore, a series of sensitivity runs were performed to examine the effects of these differences in maturity and fecundity. Preliminary models with an age-12 median age of maturity did not converge. It was therefore assumed that maximum age was proportional to the age of maturity [i.e., maximum age of 60 years ($\frac{12}{5} X\ 25\ years$)] and a corresponding natural mortality rate of 0.0757 (Section 2.3.2). Lower natural mortality rates allowed the models with an age-12 median age-of-maturity to converge. Preliminary models with triennial reproductive cycles did not converge (even with lower natural mortality rates) and were therefore discarded.

Changing the maturity and fecundity schedules resulted in substantial differences in the trend and scale of the estimated population dynamics (Table 6.1 and Fig. 6.9). Assuming a biennial reproductive cycle is identical to halving the fecundity from four to two pups per female, which resulted in an approximate doubling of the estimated number of mature females to maintain the reproductive output (i.e., number of pups produced) of the stock at about the same level. This increase in the population size also resulted in a substantial increase in the estimated MSY (Table 6.1). Increasing the median age-of-maturity to 12 years appeared to slow the initial decline and subsequent recovery in the estimated number of mature females, even though the peak fishing intensities were highest for these runs. The slower initial decline was due to the dome-shaped selectivity of the primary commercial fisheries, which reduced the availability of mature females to these fisheries as age-of-maturity increased. However, the female sharks also took a longer time to mature, which resulted in a relatively slow recovery (Fig. 6.9). With an age of maturity of 12 years, the population was estimated to be in a substantially poorer condition in 2014 (S_{2014}/S_0: 0.636) than the base case model (S_{2014}/S_0: 0.944). If both the maturity and fecundity schedules of the population were changed, the estimated number of mature females had a similar trend to the age-12 median age-of-maturity model but with a higher population scale due to the lower fecundity (Fig. 6.9).

6.1.4 Alternative data sources and weightings

6.1.4.1 Including S6 as juvenile index

In the base case model, abundance indices based on the USDGN (S1, S2, and S3) and USSN (S4 and S5) fisheries were used to represent the sub-adult/adult and recruitment population trends respectively. In addition, an abundance index from the USA juvenile thresher survey (S6) was available but not used in the base case model (Section 2.2). The effect of fitting to the S6 index was investigated in this sensitivity run. There were negligible differences in the estimated population dynamics between the base case model and including the S6 index (Table 6.1 and Fig. 6.10). The negligible influence of S6 was expected because of the large input CVs (mean input CV = 0.485) that were estimated by jack-knifing the data set.

6.1.4.2 Maximum weighting factors >1

In the base case model, the variance adjustment factors of the size composition and conditional age-at-length data were based on estimated Francis (2011) weights but were also limited to a maximum of 1 in order to limit the influence of these data on estimated population scale (Maunder and Piner 2015). However, such a procedure may lead to the under-weighting of these data, and result in potential bias and inappropriate uncertainty. In this sensitivity analysis, we allow the weighting factors of the size composition and conditional age-at-length data to be >1. Reweighting with estimated Francis weights were performed twice.

Preliminary model runs with weighting factors >1 for the size composition data of the USA juvenile thresher survey (S6) and the USSN (F3) fleet did not converge with positive definite Hessian matrices. Therefore, we also performed a run with the weighting factors for the size composition data of the S6 survey and the F3 fleet set at 1 while the other size composition data were allowed to have weighting factors >1.

The effect of allowing the maximum weighting factors to be >1 were limited (Table 6.1 and Fig. 6.11). The trend and scale of the estimated population dynamics in the sensitivity runs were highly similar to the base case model. However, the estimated 95% confidence intervals were slightly smaller in the sensitivity runs.

6.1.4.3 Down-weighting size composition data

Inappropriate weighting, especially over-weighting, of size composition data can result in biased results (Francis 2011; Maunder and Piner 2015). A series of sensitivity runs were performed to examine the influence of size composition data from each fleet on the estimated population dynamics. The size composition data from each fleet (F1, F2, F3, F8, S6) were down-weighted by a weighting factor of 0.2 in turn. Down-weighting the size composition data resulted in similar estimated population dynamics to the base case model (Table 6.1 and Fig. 6.12). The size composition data from the USDGN (F1) fleet had the largest influence because it had the largest amount of size composition data. Down-weighting the size composition data of the USSN (F3) fleet resulted in a non-positive definite Hessian matrix.

6.1.4.3 Up-weight conditional age-at-length data

The conditional age-at-length data in the base case model were down-weighted by a weighting factor of 0.2 to reduce the influence of these data on the estimated population dynamics while maintaining the ability to estimate growth inside the model. Here, we examined the sensitivity of model results to this decision by allowing the data to be fully weighted (i.e., weighting factor of 1). Model results were largely insensitive to this change in data weighting (Table 6.1 and Fig. 6.13). However, the estimated growth for female sharks were different from the base case model. If the conditional age-at-length were fully weighted, the estimated L_∞ was larger than the base case model (269.9 cm vs 251.9 cm) and a concomitantly smaller K (0.1145 y^{-1} vs 0.1286 y^{-1}). Differences in the estimated growth of male sharks were smaller than for female sharks.

6.1.5 Alternative assumptions on selectivity

6.1.5.1 Alternative time blocks

Regulatory changes, especially different time-area closures, likely affected the fishing operations of the USDGN and USSN fisheries, and hence changed the selectivities of the F1, F2, and F3 fleets over time. In the base case model, we accounted for this by allowing selectivities of these three fleets to vary over time in time blocks defined by regulatory changes. However, alternative time periods may be used to define the selectivity time blocks. In this sensitivity model, we simplified the selectivity time blocks for the F1 (1969 – 1984, 1985 – 2000, and 2001 – 2014) and F2 (1969 – 1984, and 1985 – 2014) fleets (cf. Table 3.1). The estimated scale of the population dynamics for this sensitivity model were highly similar to the base case model. However, the population trajectories of the two models differed during a middle period from the mid-1980s to the mid-2000s. In this sensitivity model, the population reached a lower level in the mid-1980s but began to recover from that point. In contrast, the base case model population stabilized at that point in time but did not begin increasing consistently till about 2000. Over the last 10 years of the time series, both models exhibited highly similar trends with minimal differences.

6.1.5.2 Size selectivity for F3

In the base case model, the USSN (F3) fleet was assumed to have an age-based selectivity and used an aggregated age-0 size bin because of the difficulty in fitting the size composition data with a reasonable size-based selectivity process. In this sensitivity run, the effect of this decision was explored by using a size-based selectivity process for the F3 fleet and not aggregating the age-0 size bins into a single bin. The estimated selectivity and model fits indicated relatively poor model fit to the data in the sensitivity run (Fig. 6.15). However, the effect on the estimated population dynamics was relatively minor, with only a period between the mid-1980s to the mid-1990s showing any obvious differences. Differences in other periods appeared to be negligible.

6.1.5.3 Estimate F6 selectivity

The selectivity of the MXDGN (F6) fleet was assumed to be the same as the USDGN (F1) fleet in the base case model because of difficulty in fitting the limited size composition data in preliminary models and similarities in fishing gear and operations for both fleets. In this sensitivity run, the selectivity of the F6 fleet was estimated and we examined the effect of doing so on the estimated population dynamics. The estimated selectivity for F6 was highly similar to that of F1, albeit without any time blocks due to the limited size composition data, and there were minimal differences in the estimated population dynamics (Fig. 6.16).

6.1.5.4 Alternative spline parameterization for F2

The size selectivity of the USDGNs2 (F2) fleet was parameterized as a spline with knots at four fixed locations in the base case model (Table 5.1). However, preliminary models indicated that the estimated selectivity could be sensitive to the location of the knots, especially the final knot. In these sensitivity runs, the location of the final knot was shifted from 225 cm to 215 and 235 cm to examine the effects on the estimated population dynamics. The most important effect appeared to be on the estimated selectivity for the 1985 – 1988 time block but had negligible effects on the estimated population dynamics (Fig. 6.17).

7. Reference points

The current USA fishery management plan for USA West Coast fisheries associated with highly migratory species (PFMC 2011b) uses status determination criteria (SDC) for common thresher shark that are based on MSY, with overfishing occurring if the estimated current fishing mortality or a reasonable proxy exceeds the maximum fishing mortality threshold (MFMT) defined as F_{MSY} or a reasonable proxy; and the stock declared in an overfished condition if current spawning biomass is less than the minimum stock size threshold (MSST) defined as (1-M)*B_{MSY}, when $M \leq 0.5$ and M is the instantaneous rate of natural mortality. Based on an unpublished assessment of the USA portion of the stock, a harvest guideline of 340 t was established using the alternative optimum yield (OY) control rule for vulnerable species (i.e., 0.75*MSY) (PFMC 2011b).

For the base case model of this assessment, the estimated MSY for this stock was 806.5 t (95% CI: 614.7 – 998.3 t), and the number of mature female sharks at MSY was estimated to be 43,500 sharks (95% CI: 34,600 – 52,400 sharks), with a reproductive output of 174,000 pups (95% CI: 138,300 – 209,700 pups) (Table 7.1). The fishing intensity (1-SPR) corresponding to MSY was estimated at 0.39 (95% CI: 0.37 – 0.40). Based on these estimates, the MFMT was 0.39 (using 1 – SPR_{MSY} as a proxy for F_{MSY}) and the MSST was 35,700 mature female sharks (Table 7.1).

8. Status of the stock

The estimated fishing intensity (1-SPR) on the common thresher sharks off the west coast of North America is currently relatively low at 0.08 (average of 2012 – 2014) (Table 5.2) and substantially below the estimated overfishing threshold (MFMT), with $(1\text{-}SPR_{1214})/(1\text{-}SPR_{MSY})$ at 0.21 (Table 8.1 and Fig.8.1). Similarly, the estimated number of mature female sharks in 2014 (S_{2014}) for this stock is at 94% of its unexploited level and is substantially larger than the estimated MSST, with S_{2014}/MSST at 2.33 (Table 8.1 and Fig.8.1). Thus, this stock of common thresher sharks is unlikely to be in an overfished condition nor experiencing overfishing.

The stock experienced a relatively large and quick decline in the late 1970s and early 1980s, soon after the onset of the USA swordfish/shark drift gillnet fishery, with spawning depletion dropping to 0.4 in 1985 (Table 5.2 and Fig. 5.8). The population appeared to have stabilized in the mid-1980s after substantial regulations were imposed. Over the past 15 years, the stock began recovering relatively quickly and is currently close to an unexploited level.

Besides the base case model, the status of the stock was also examined under three alternative states of nature, based on alternative reproductive biology and stock-recruitment assumptions: 1) alternative reproductive biology with a biennial reproductive cycle, 12 years median age-at-maturity, and natural mortality of 0.0757; 2) alternative stock-recruitment with z_{frac} of 0.4; and 3) alternative stock-recruitment with z_{frac} of 0.8 (Table 8.1). These alternative states of nature addressed the most important sources of uncertainty identified in the sensitivity analysis (Sections 6.1.2.1 and 6.1.3.3). The estimated management quantities from models assuming these alternative states of nature all indicated that this stock of common thresher sharks is unlikely to be in an overfished condition nor experiencing overfishing (Table 8.1 and Fig. 8.2).

9. Decision table

The same four states of nature used to examine stock status were also used in model projections: 1) the base case model; 2) alternative reproductive biology with a biennial reproductive cycle, 12 years median age-at-maturity, and natural mortality of 0.0757; 3) alternative stock-recruitment with z_{frac} of 0.4; and 4) alternative stock-recruitment with z_{frac} of 0.8 (Table 9.1). These alternative states of nature addressed the most important sources of uncertainty identified in the sensitivity analysis (Sections 6.1.2.1 and 6.1.3.3).

Ten-year forecasts for each state of nature were calculated based on three future removal scenarios: 1) average catch for 2012 – 2014 in the base case model; 2) 2 * the average catch for 2012 – 2014 in the base case model; and 3) total annual catch of USA swordfish/shark drift gillnet and recreational fisheries (i.e., F1, F2, F4, and F5) at the 340 t PFMC harvest guideline and remaining fisheries at their average catch for 2012 – 2014.

A decision table with these future removal scenarios and alternative states of nature is provided in Table 9.1. For all states of nature and removal scenarios, the adult population is expected to continue increasing and stock depletion is expected to continue improving over the next several years. For the base case and alternative stock-recruitment states of nature, the adult population starts to decline after several years because the fisheries on common thresher sharks primarily catch juvenile and sub-adult sharks and a lag of several years is needed before changes are evident in the adult population. For the alternative reproductive biology model, a lag longer than 10 years (timespan of the forecasts) is needed before changes in the adult population are evident because of the older median age-at-maturity.

10. Regional management considerations

Common thresher sharks are migratory, large pelagic sharks and this stock along the west coast of North America is abundant from Baja California, Mexico to Washington, USA. This stock assessment included data from both USA and Mexico waters, encompassing the predominant range of the stock. Small numbers of common thresher sharks are caught by Canada fisheries but the catch is small enough to be negligible. Although this stock assessment encompasses the entire stock, management of this stock is dependent on the domestic regulations of the USA and Mexico, which are largely uncoordinated. However, catch and effort from both USA and Mexico fisheries have been relatively low in recent years compared to historical catch and effort.

11. Research and data needs

In this stock assessment, several critical assumptions were made based on limited supporting data and research. There are several research and data needs that if satisfied could improve future assessments, including:

1. The reproductive biology of this stock of common thresher sharks requires further research. Previous research on the reproductive biology of this common thresher shark stock suggested that the median age of maturity for female sharks was 5 years of age and that common thresher sharks had an annual reproductive cycle (Smith et al. 2008a,b). However, a recent study on the reproductive biology of the western North Atlantic stock of common thresher sharks (Natanson and Gervelis 2013) demonstrated a much higher median age of maturity for female sharks (age-12) and longer reproductive cycle (biennial or triennial cycle) for that stock. Sensitivity model runs indicated that changing the maturity and fecundity schedules resulted in substantial differences in the estimated trend and scale of the estimated population dynamics, and was one of the most important assumptions in this assessment. Therefore, it is important that research be conducted to re-examine the maturity ogive and reproductive schedule of this stock. A comparative study between this and the western North Atlantic stock should also be conducted to examine and explain major observed differences in reproductive biology.
2. The survey design and protocols of the USA juvenile thresher shark survey should be re-examined and improved. In this stock assessment, the abundance index derived from the

USA juvenile thresher shark survey was not fit in the base case model because: 1) current protocols resulted in fishing operations that resembled commercial fishing operations with variable effort and catchability; 2) spatial coverage of the survey was relatively limited and likely covered only a small portion of the juvenile range; and 3) fishing effort of the survey was relatively low and the patchy distribution of common thresher sharks resulted in highly variable abundance index estimates (i.e., high CV). The design and protocols of the USA juvenile thresher shark survey should be re-examined to reduce these current drawbacks.

3. Catch and catch-at-size estimates from USA fisheries, especially the USA recreational fishery, should be improved. The USA recreational fishery on this stock of common thresher sharks consists mostly of private vessels, which are poorly sampled. Besides the usual difficulties in estimating the catch, there is also virtually no data on the size composition of the catch. In this assessment, the size of fish caught by the recreational fishery was assumed to be similar to that caught by the USDGN fishery but this assumption may be inappropriate. Therefore, some effort should be put into sampling the recreational catch in the near future. In addition, size composition data from the USSN fishery have also been lacking in recent years.
4. Catch and catch-at-size estimates from Mexico fisheries should be improved. The catch of common thresher shark from Mexico fisheries were estimated for this assessment because of the lack of historical species-specific catch data for sharks. In addition, the collection of size composition data for common thresher shark from Mexico fisheries was ad hoc and opportunistic. Improving future data collection from Mexico fisheries will be difficult but likely to result in improvements to future stock assessments.
5. The use of the low fecundity stock recruitment relationship requires further research. The low fecundity stock recruitment relationship has only been developed recently and has not been thoroughly investigated. In this assessment, we assumed a fixed level for z_{frac} and estimated the shape parameter. Preliminary model simulations suggested that the data in the assessment was adequate to estimate the shape parameter but more thorough examination of the use of this stock recruitment relationship is required.

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TABLES

Table 1.1. Timeline of major changes in regulations and operations of the USA and Mexico swordfish/shark drift gillnet fisheries (USDGN and MXDGN), USA nearshore set gillnet and small-mesh drift gillnet fishery (USSN), and Mexican pelagic longline fishery (MXLL).

Year	Regulation or operational change
	USA swordfish/shark drift gillnet fishery (USDGN)
1977	Initial development of swordfish/shark drift gillnet fishery in Southern California, initially targeting pelagic sharks. Swordfish landings not authorized.
1980	Drift gillnet gear restrictions established with minimum mesh size of 8 inches, twine size at #18, and net length or 6000 feet or less. Nets could be fished only between 2 h before sunset and 2 h after sunrise. Swordfish landings for any given month limited to 25% of the number of swordfish landed by harpoon fishery for that month. Marlin bycatch limited to 10% of the number of marlin caught by recreational fishery for any given month.
1982	Minimum mesh size changed to 14 inches. Limited time-area closure (May 1 through July 31) around Channel Islands and between Channel Islands and mainland (February 1 through April 30). Swordfish (25% of harpoon fishery) and marlin (10% of recreational fishery) quotas replaced by limits on swordfish landings to no more than the landings of thresher and mako sharks for any permit holder during any given month during May 1 through September 15.
1983	Initial development of swordfish/shark drift gillnet fishery in Washington and Oregon. Experimental drift gillnet permits issued by Washington and Oregon.
1985	New time-area closures in California. Drift gillnets were prohibited within 75 nm of the California mainland from 1 June through 14 August, to reduce fishing pressure on thresher sharks; and within 25 nm from 15 December through 31 January to protect gray whales. Equal shark-swordfish landing requirement eliminated.
1986	California prohibited drift gillnet fishery within 12 nm of the California coast north of Point Arguello and certain areas in the Gulf of the Farallones. First substantial landings of thresher shark in Washington and Oregon ports (~293 mt dressed weight).
1989	Drift gillnet thresher shark fishery closed in Washington and Oregon. Closure period for 75 nm time-area closure in California (see 1985) changed to May 1 through July 14.
1990	Mandatory observer program for the USA swordfish/shark drift gillnet fishery began.
1992	Closure period for 75 nm time-area closure in California (see 1985) changed to May 1 through August 14.
2001	Additional time-area closures established by the NMFS. The drift gillnet fishery was closed from August 15 through November 15 in an area between Point Conception and 45 °N to protect leatherback sea turtles. In addition, if an El Nino is occurring, or predicted to occur, the area south of Point Conception will be closed to drift gillnet fishing from August 15 to August 31, and during the entire month of January, to reduce loggerhead sea turtle impacts.
2003	USA Pacific States Marine Fisheries Commission finalized coastwide thresher shark management plan. Harvest guideline of 340 t established for USA West Coast fisheries.

Table 1.1. continued.

Year	Regulation or operational change
	USA nearshore set gillnet and small mesh drift gillnet fisheries
1994	All gillnets and trammel nets prohibited within 3 nm of California mainland and within 1 nm (or waters < 70 fathoms depth) of Channel Islands (California Marine Resources Protection Act, 1990).
	Mexico swordfish/shark drift gillnet fishery
1983	50 nm sportsfishing-only zone along Mexico coast.
1986	Start of fishery.
2010	End of fishery due to Mexico federal regulations.
	Mexico pelagic longline fishery
1976	Declaration of Mexico EEZ. All longline permits withdrawn.
1980	Mexico-Japan joint venture longline fishery started.
1983	50 nm sportsfishing-only zone along Mexican coast.
1990	Mexico-Japan joint venture longline fishery ended.
1997	Mexico DGN vessels begin converting to longline gear.

Table 2.1. Description of fleets and abundance indices in the base case model.

Fleet ID	Short name	Fleet description
		Fleets with removals
F1	USDGN	USA swordfish/shark pelagic drift gillnet fishery for seasons 1, 3, and 4. Removals from USA miscellaneous fisheries for these seasons were included into this fleet.
F2	USDGNs2	USA swordfish/shark pelagic drift gillnet fishery for season 2. Removals from USA miscellaneous fisheries for season 2 were included into this fleet.
F3	USSN	USA nearshore set gillnet and small-mesh drift gillnet fishery for all 4 seasons.
F4	USREC	USA recreational fishery for seasons 1, 3, and 4. Catch units in number of fish.
F5	USRECs2	USA recreational fishery for season 2. Catch units in number of fish.
F6	MXDGNLL	Mexico swordfish/shark pelagic drift gillnet fishery for seasons 1, 3, and 4. Removals from the Mexico pelagic longline fishery for these seasons were included in this fleet.
F7	MXDGNLLs2	Mexico swordfish/shark pelagic drift gillnet fishery for season 2. Removals from the Mexico pelagic longline fishery for this season were included in this fleet.
F8	MXART	Mexico coastal artisanal fishery with mixed gillnet and longline gears. Also known as the panga fishery.
		Abundance indices inputted as surveys
S1	USDGN8284	Standardized annual index of relative abundance of sub-adult/adult common thresher sharks based on logbooks from the USA swordfish/shark pelagic drift gillnet fishery during 1982 – 1984.
S2	USDGN9200	Standardized annual index of relative abundance of sub-adult/adult common thresher sharks based on logbooks from the USA swordfish/shark pelagic drift gillnet fishery during 1992 – 2000.
S3	USDGN0113	Standardized annual index of relative abundance of sub-adult/adult common thresher sharks based on logbooks from the USA swordfish/shark pelagic drift gillnet fishery during 2001 – 2013.
S4	USSN8593	Standardized annual index of relative abundance of primarily age-0 common thresher sharks based on logbooks from the USA nearshore set gillnet and small-mesh drift gillnet fishery during 1985 – 1993.
S5	USSN9414	Standardized annual index of relative abundance of primarily age-0 common thresher sharks based on logbooks from the USA nearshore set gillnet and small-mesh drift gillnet fishery during 1994 – 2014.
S6	USJUV0614	Standardized annual index of relative abundance of juvenile common thresher sharks from a coastal longline survey conducted by the Southwest Fishery Science Center during 2006 – 2014.

Table 2.2. Estimated common thresher shark removals by fleet.

Year	USDGN (t)	USDGNs2 (t)	USSN (t)	USREC (1000 fish)	USRECs2 (1000 fish)	MXDGNLL (t)	MXDGNLLs2 (t)	MXART (t)
1969	84.4	17.4	1.8	0.6	0.6	0.0	0.0	20.9
1970	87.0	32.3	2.8	0.6	0.6	0.0	0.0	20.9
1971	21.4	39.8	2.4	0.6	0.6	0.0	0.0	20.9
1972	99.3	20.4	2.5	0.6	0.6	0.0	0.0	20.9
1973	42.0	70.8	1.2	0.6	0.6	0.0	0.0	20.9
1974	120.9	23.4	2.5	0.6	0.6	0.0	0.0	20.9
1975	143.9	97.2	5.1	0.6	0.6	0.0	0.0	20.9
1976	263.9	133.5	7.7	0.6	0.6	0.0	0.0	29.4
1977	246.1	167.0	8.9	0.6	0.6	0.0	0.0	16.8
1978	322.8	254.1	31.9	0.6	0.6	0.0	0.0	16.5
1979	745.2	380.3	55.5	0.6	0.6	0.0	0.0	21.1
1980	1638.8	486.4	36.1	0.4	0.0	0.0	0.0	39.7
1981	842.1	747.9	74.1	0.1	0.0	0.0	0.0	54.5
1982	963.0	846.7	143.4	1.9	0.2	0.0	0.0	84.7
1983	438.1	835.5	67.3	0.5	3.0	0.0	0.0	74.1
1984	447.3	754.3	102.3	0.6	0.0	0.2	0.0	47.6
1985	241.8	890.7	65.9	0.2	0.2	6.6	2.7	16.6
1986	661.0	325.9	8.8	1.4	0.0	27.8	11.8	30.7
1987	303.0	285.0	15.4	0.8	4.1	88.7	40.1	38.9
1988	432.6	134.5	3.7	0.0	0.9	102.5	47.0	43.6
1989	335.3	114.4	3.0	0.8	0.0	74.1	32.2	21.5
1990	337.7	104.6	3.9	0.0	0.0	174.1	79.6	32.9
1991	310.0	147.7	2.8	0.0	0.0	147.5	65.4	18.9
1992	138.9	154.9	2.4	0.0	0.0	266.1	120.8	32.3
1993	237.6	38.0	3.0	1.9	0.9	280.5	127.9	20.3
1994	280.5	63.5	9.3	1.9	1.7	245.9	112.8	17.7
1995	210.3	56.2	10.3	2.2	0.5	173.9	78.0	12.8
1996	278.4	84.5	10.7	0.1	0.6	248.4	112.5	18.1
1997	200.8	55.0	14.8	0.3	0.1	279.3	126.1	20.6
1998	271.3	84.8	13.2	0.6	0.5	325.2	148.8	26.5
1999	194.2	110.8	19.6	0.8	0.3	185.3	81.9	18.1
2000	174.6	106.1	30.7	1.5	0.8	227.8	98.9	30.9
2001	239.3	99.7	27.8	1.6	0.6	205.9	87.0	35.1
2002	266.3	88.2	22.5	0.7	1.0	197.9	83.7	33.7
2003	134.9	73.0	15.8	0.5	1.7	188.8	77.9	32.6
2004	63.8	23.9	16.7	4.2	0.3	285.5	122.2	48.3
2005	155.9	29.2	9.2	0.2	0.1	181.8	76.6	31.1
2006	110.0	31.4	18.4	0.2	0.8	189.2	79.5	32.4
2007	165.0	25.0	9.7	0.9	0.6	208.5	87.7	35.9
2008	117.9	19.7	12.9	0.7	0.5	208.6	87.5	42.2
2009	58.4	27.9	12.8	1.5	0.4	54.4	10.1	48.5
2010	54.9	22.8	16.5	0.4	0.8	48.8	9.1	43.6
2011	82.3	4.9	9.5	1.7	0.7	41.4	7.5	36.5
2012	49.0	11.2	7.4	0.3	0.1	47.3	8.6	41.9
2013	42.8	8.5	3.2	0.2	0.6	44.9	9.1	41.4
2014	12.9	19.2	5.4	0.2	0.3	44.5	8.4	39.9

Table 2.3. Indices of relative abundance and associated coefficients of variation (CV). Units are number of fish per unit effort.

	USDGN8284 S1		USDGN9200 S2		USDGN0113 S3		USSN8593 S4		USSN9414 S5		USJUV0614 S6	
Year	**Index**	**CV**	**Index**	**CV**	**Index**	**CV**	**Index**	**CV**	**Index**	**CV**	**Index**	**CV**
1981												
1982	0.01229	0.28035										
1983	0.00921	0.27814										
1984	0.00763	0.27842										
1985							0.07149	0.22246				
1986							0.05076	0.22000				
1987							0.07998	0.23149				
1988							0.06265	0.23024				
1989							0.04039	0.23056				
1990							0.07087	0.23840				
1991							0.05103	0.23477				
1992			0.00047	0.11681			0.06788	0.24198				
1993			0.00066	0.11289			0.08320	0.23061				
1994			0.00107	0.11289					0.20827	0.25464		
1995			0.00076	0.12739					0.20266	0.23268		
1996			0.00099	0.12568					0.29486	0.21991		
1997			0.00112	0.11994					0.45911	0.19964		
1998			0.00214	0.12047					0.49911	0.20750		
1999			0.00126	0.12996					0.55780	0.19030		
2000			0.00191	0.14880					0.33207	0.20322		
2001					0.01269	0.19702			0.69024	0.21287		
2002					0.00631	0.20242			0.38927	0.22537		
2003					0.00575	0.21192			0.22220	0.20489		
2004					0.00518	0.21691			0.29735	0.20710		
2005					0.01830	0.20352			0.24872	0.22886		
2006					0.00687	0.19910			1.00752	0.19227	3.20419	0.54869
2007					0.02289	0.19697			0.69005	0.20402	1.70947	0.51328
2008					0.00685	0.22096			0.38999	0.21220	7.64873	0.46797
2009					0.00391	0.22504			0.69659	0.19518	3.04584	0.47143
2010					0.01745	0.23111			0.76876	0.19815	5.43268	0.43013
2011					0.01148	0.23021			0.51435	0.21067	8.82981	0.49681
2012					0.00711	0.22832			0.72856	0.19746	4.87355	0.45691
2013					0.01244	0.19884			0.21324	0.24029	5.18471	0.45535
2014									0.81005	0.41220	1.73476	0.52305

Table 2.4. Summary of sampling effort used to generate size compositions for the assessment by fleet, length type measured (alternate or fork length), and year. Alternate length samples are shown in italic, while fork length samples are shown in standard type.

	USDGN (F1 & F2)		**USSN (F3)**		**USJUV0614 (S6)**		**MXDGN (F6 & F7)**		**MXART (F8)**	
Year	**N trips**	**N fish**	**N trips**	**N fish**	**N sets**	**N fish**	**N trips**	**N fish**	**N trips**	**N fish**
1981	*64*	*1093*								
1982	*175*	*1224*								
1983	*178*	*1528*	*1*	*11*						
1984	*146*	*1292*	*8*	*21*						
1985	*126*	*977*								
1986	*142*	*802*	*18*	*38*						
1987	*97*	*678*	*14*	*44*						
1988	*168*	*820*	*6*	*34*						
1989	*113*	*1024*	*15*	*98*						
1990	28	221	10	27						
1991	26	285	30	54						
1992	28	230	32	87						
1993	23	286	55	87						
1994	51	582	8	9						
1995	23	174								
1996	32	691								
1997	57	516								
1998	51	757								
1999	40	314	11	22						
2000	42	683	1	1						
2001	41	611								
2002	33	414								
2003	31	440								
2004	29	162								
2005	37	959								
2006	26	218	2	10	29	236				
2007	20	173	3	6	22	129	*6*	*743*		
2008	15	165			39	280	*3*	*612*		
2009	7	50	3	10	32	200				
2010	8	1015	15	32	33	277				
2011	17	402	7	15	38	393			NA	349
2012	6	88	12	51	38	265				
2013	20	167	2	3	36	262				
2014					23	138				

Table 3.1. Selectivity patterns used in the base case model. Estimated parameters can be found in Table 5.1.

Fleet ID	Fleet name	Time periods	Selectivity pattern
Estimated selectivity			
F1	USDGN	1969 – 1981	Double-normal size selectivity
		1982 – 1984	
		1985 – 1988	
		1989 – 1991	
		1992 – 2000	
		2001 – 2014	
F2	USDGNs2	1969 – 1981	4-knot spline size selectivity
		1982 – 1984	
		1985 – 1988	
		1989 – 2014	
F3	USSN	1969 – 1993	Age selectivity; age-0 to 2 freely estimated; age-3+ at 0 selectivity
		1994 – 2014	
F8	MXART	1969 – 2014	Double-normal size selectivity
S6	USJUV0614	1969 – 2014	Double-normal size selectivity
Mirrored selectivity			
F4	USREC		Mirrored to F1
F5	USRECs2		Mirrored to F2
F6	MXDGNLL		Mirrored to F1
F7	MXDGNLLs2		Mirrored to F2
S1	USDGN8284		Mirrored to F1
S2	USDGN9200		Mirrored to F1
S3	USDGN0113		Mirrored to F1
S4	USSN8593		Mirrored to F3
S5	USSN9414		Mirrored to F3

Table 4.1. Analytical estimates of catchability, mean input variance, variance adjustment, and model fit (root mean square error, RMSE of expectations to observations) for sub-adult/adult (S1, S2, and S3) and recruitment (S4 and S5) annual abundance indices in the base case model.

Index	**Years**	**Catchability**	**Mean input CV**	**Variance adjustment**	**Input CV + Var. Adj.**	**RMSE**
S1	1982-1984	1.27E-4	0.279	0	0.279	0.157
S2	1992-2000	1.39E-5	0.124	0.266	0.390	0.391
S3	2001-2013	6.98E-5	0.212	0.332	0.545	0.545
S4	1985-1993	7.68E-4	0.231	0	0.231	0.176
S5	1994-2014	5.35E-3	0.221	0	0.221	0.178

Table 4.2. Mean input variances (input N after variance adjustment) and model estimated mean variance (*effN*) of the size composition data components of the base case model. Harmonic mean of the *effN* and the ratio of the harmonic mean of *effN* to the mean input N are also provided. A higher *effN* indicates a better model fit. Number of observations corresponds to the number of quarters in which size composition data were sampled. Number of observations for F8 is not applicable (NA) because a super year was used to aggregate the size compositions for the fleet.

Fleet	**Bin structure**	**Number of observations**	**Mean input N after var adj**	**Mean *effN***	**Harmonic mean *effN***	**Harmonic mean *effN*/ mean inputN**
F1	2 cm	43	14.9	104.2	39.0	2.6
F1	7 cm	21	40.9	95.3	62.7	1.5
F2	2 cm	2	7.5	107.3	96.2	12.8
F2	7 cm	9	40.3	187.3	139.2	3.5
F3	Age-0	20	10.5	31.9	14.4	1.4
F8	2 cm	NA	3.0	143.5	143.5	47.8
S6	2 cm	9	32.2	284.8	256.8	8.0

Table 4.3. Mean input variances (input N after variance adjustment) and model estimated mean variance (*effN*) of the conditional age-at-length data components of the base case model. Harmonic mean of the *effN* and the ratio of the harmonic mean of *effN* to the mean input N are also provided. A higher *effN* indicates a better model fit. Number of observations corresponds to the number of sharks sampled in a fishery.

Fleet	**Number of observations**	**Mean input N after var adj**	**Mean *effN***	**Harmonic mean *effN***	**Harmonic mean effN/ mean inputN**
F1	151	1.2	1.6	1.2	1.0
F3	1	1.0	9.0	9.0	9.0

Table 5.1. List of parameters used in the base case model. Sex-specific parameters are indicated by having female and male parameters, otherwise parameter values are the same for either gender.

Parameter		Value	Min	Max	Fixed	Estimation Phase
Natural Mortality		0.179			x	
Growth						
Female	L1	71.3	30	100		5
	L_∞	251.9	200	300		5
	K	0.129	0	0.2		5
	CV1	0.08			x	
	CV2	0.05			x	
Male	Offset from female L1	4.43E-3	-2	2		5
	Offset from female L_∞	-0.0118	-2	2		5
	Offset from female K	-0.0233	-2	2		5
	Offset from female CV1	0			x	
	Offset from female CV2	0			x	
Weight-at-length						
	Coefficient	1.88E-4			x	
	Exponent	2.519			x	
Reproduction						
	Last age at 0% maturity	4			x	
	Age at 50% maturity	5			x	
	First age at 100% maturity	6			x	
	Fecundity at length intercept	4			x	
	Fecundity at length slope	0			x	
Stock-recruitment						
	$\log(R_0)$	4.345	1	15		1
	z_{frac}	0.6			x	
	Beta	3.059	0.4	7		1
Initial fishing mortality						
	F1	0.0238	0	3		1
	F2	0			x	
	F3	0			x	
	F4	0.0222	0	3		1
	F5	0			x	
	F6	0			x	
	F7	0			x	
	F8	0.0445	0	3		1
Size selectivity (F1: 1969 – 1981)						
	Peak	156.9	45	250		2
	Top	-4			x	
	Ascending width	6.494	-4	12		3
	Descending width	8.070	-4	12		3
	Selectivity at first bin	-2.248	-9	9		4
	Selectivity at last bin	-1000			x	

Table 5.1 (continued). List of parameters used in the base case model

Parameter	Value	Min	Max	Fixed	Estimation Phase
Size selectivity (F1: 1982 – 1984)					
Peak	154.3	45	250		5
Top	-4			x	
Ascending width	6.369	-4	12		5
Descending width	7.438	-4	12		6
Selectivity at first bin	-2.424	-9	9		6
Selectivity at last bin	-1000			x	
Size selectivity (F1: 1985 – 1988)					
Peak	137.9	45	250		5
Top	-4			x	
Ascending width	6.611	-4	12		5
Descending width	7.997	-4	12		6
Selectivity at first bin	-1.474	-9	9		6
Selectivity at last bin	-1000			x	
Size selectivity (F1: 1989 – 1991)					
Peak	130.3	45	250		5
Top	-4			x	
Ascending width	6.575	-4	12		5
Descending width	7.883	-4	12		6
Selectivity at first bin	0.236	-9	9		6
Selectivity at last bin	-1000			x	
Size selectivity (F1: 1992 – 2000)					
Peak	160.8	45	250		5
Top	-4			x	
Ascending width	6.585	-4	12		5
Descending width	7.524	-4	12		6
Selectivity at first bin	-4.053	-9	9		6
Selectivity at last bin	-1000			x	
Size selectivity (F1: 2001 – 2014)					
Peak	163.6	45	250		5
Top	-4			x	
Ascending width	6.756	-4	12		5
Descending width	7.279	-4	12		6
Selectivity at first bin	-3.865	-9	9		6
Selectivity at last bin	-1000			x	
Size selectivity (F2: 1969 – 1981)					
Spline gradient low: all periods	0.067	-1	1		3
Spline gradient high: all periods	-0.066	-1	1		3
Spline knot 1: all periods	75			x	
Spline knot 2: all periods	125			x	
Spline knot 3: all periods	175			x	
Spline knot 4: all periods	225			x	

Table 5.1 (continued). List of parameters used in the base case model

Parameter	Value	Min	Max	Fixed	Estimation Phase
Size selectivity (F2: 1969 – 1981) continued					
Spline value at knot 1	-3.134	-9	9		3
Spline value at knot 2	-0.579	-9	9		3
Spline value at knot 3: all periods	0			x	
Spline value at knot 4	-3.100	-9	9		3
Size selectivity (F2: 1982 – 1984)					
Spline value at knot 1	-3.260	-9	9		6
Spline value at knot 2	-0.739	-9	9		6
Spline value at knot 4	-1.934	-9	9		6
Size selectivity (F2: 1985 – 1988)					
Spline value at knot 1	-1.091	-9	9		6
Spline value at knot 2	-0.101	-9	9		6
Spline value at knot 4	0.078	-9	9		6
Size selectivity (F2: 1989 – 2014)					
Spline value at knot 1	-1.720	-9	9		6
Spline value at knot 2	0.980	-9	9		6
Spline value at knot 4	-1.285	-9	9		6
Age selectivity (F3: 1969 – 1993)					
Age-0	5.825	-9	9		2
Age-1	-3.627	-9	9		2
Age-2	-4.357	-9	9		2
Age-3 to age-25: all periods	-99			x	
Age selectivity (F3: 1993 – 2014)					
Age-0	6.981	-9	9		2
Age-1	-5.697	-9	9		2
Age-2	-5.270	-9	9		2
Size selectivity (F8)					
Peak	79.6	45	250		2
Top	-4			x	
Ascending width	4.135	-4	9		3
Descending width	6.733	-4	9		3
Selectivity at first bin	-1000			x	
Selectivity at last bin	-1000			x	
Size selectivity (S6)					
Peak	84.7	45	250		2
Top	-4			x	
Ascending width	4.135	-4	9		3
Descending width	6.733	-4	9		3
Selectivity at first bin	-1000			x	
Selectivity at last bin	-1000			x	

Table 5.2. Total biomass (Q1, age-1+), biomass and number of mature female sharks (Q2), depletion (S/S_0), recruitment, and fishing intensity (1-SPR) estimated in the base case model. Estimated virgin number of mature female sharks (S_0) and recruitment were 88,200 and 77,100 fish respectively. Reproductive output in number of pups was 4 * number of mature females.

Year	Total biomass age-1+ (mt)	Biomass of mature female sharks (mt)	Number of mature female sharks (1000s)	Depletion (S/S_0)	Number of recruits (1000s)	Fishing intensity (1-SPR)
1969	29846.6	10843.2	92.9	1.053	87.13	0.079
1970	29837.1	10848.4	93.0	1.054	91.06	0.086
1971	29857.8	10848.0	92.9	1.053	88.84	0.067
1972	29920.9	10855.6	93.0	1.054	78.41	0.086
1973	29777.9	10857.0	93.0	1.054	67.99	0.086
1974	29444.4	10834.3	92.7	1.050	63.45	0.098
1975	28921.9	10825.5	92.7	1.050	61.04	0.137
1976	28179.3	10779.5	92.3	1.046	55.22	0.203
1977	27121.6	10583.0	89.9	1.019	47.43	0.211
1978	25904.8	10265.7	86.1	0.976	46.58	0.307
1979	24436.7	9755.3	80.5	0.912	66.98	0.493
1980	22663.1	8947.3	72.4	0.821	67.48	0.698
1981	20112.0	7772.6	61.2	0.694	62.48	0.698
1982	18219.0	6777.2	51.8	0.588	58.21	0.831
1983	15948.4	5861.9	43.8	0.496	81.50	0.756
1984	14676.3	5128.9	38.3	0.434	58.34	0.732
1985	13582.5	4641.3	35.2	0.399	64.57	0.614
1986	12834.1	4198.3	33.0	0.374	62.38	0.638
1987	12295.8	3912.4	31.3	0.355	62.67	0.595
1988	11926.5	3734.7	31.2	0.354	50.70	0.527
1989	11707.5	3690.1	31.6	0.358	40.70	0.455
1990	11536.8	3697.2	32.1	0.364	50.34	0.530
1991	11297.1	3737.8	32.9	0.373	56.07	0.518
1992	11171.6	3736.3	33.1	0.375	78.00	0.498
1993	11387.4	3630.6	31.9	0.362	67.68	0.565
1994	11474.0	3370.3	29.0	0.328	44.53	0.589
1995	11273.8	3137.8	26.8	0.304	45.62	0.492
1996	11262.7	3129.5	27.3	0.310	66.30	0.499
1997	11411.5	3266.8	29.9	0.339	78.06	0.465
1998	11841.7	3480.3	32.8	0.371	79.62	0.543
1999	12184.8	3473.3	32.3	0.366	96.84	0.425
2000	13110.6	3420.0	31.2	0.354	65.30	0.471
2001	13584.6	3502.3	32.3	0.367	126.88	0.438
2002	14817.7	3728.4	35.3	0.400	74.20	0.402
2003	15573.7	4034.2	38.9	0.441	42.81	0.326
2004	15928.4	4475.0	44.0	0.498	61.78	0.405

Table 5.2 (continued). Total biomass (Q1, age-1+), biomass and number of mature female sharks (Q2), depletion (S/S_0), recruitment, and fishing intensity (1-SPR) estimated in the base case model.

Year	**Total biomass age-1+ (mt)**	**Biomass of mature female sharks (mt)**	**Number of mature female sharks (1000s)**	**Depletion (S/S_0)**	**Number of recruits (1000s)**	**Fishing intensity (1-SPR)**
2005	16041.0	4753.2	46.1	0.523	49.50	0.262
2006	16216.0	5274.6	52.1	0.591	150.51	0.256
2007	17630.4	5808.1	57.0	0.646	125.69	0.291
2008	18960.3	5788.9	54.4	0.616	87.62	0.264
2009	19996.8	5750.0	52.5	0.595	113.05	0.161
2010	21518.0	5794.9	51.9	0.588	119.32	0.120
2011	23198.6	6402.2	60.3	0.683	86.68	0.138
2012	24346.1	7481.2	73.2	0.830	126.48	0.080
2013	25985.6	8158.4	78.9	0.894	46.49	0.084
2014	26499.2	8707.9	83.3	0.944	88.47	0.076

Table 6.1. Estimated number of mature females under virgin conditions (S_0), and in 2014 (S_{2014}), average fishing intensity (1-SPR) in 2012 – 2014, maximum sustainable yield (MSY), and total negative log-likelihood for sensitivity runs conducted. Note that likelihoods may not be comparable between models.

Sensitivity run description	**S_0 (1000s of fish)**	**S_{2014} (1000s of fish)**	**1-SPR 2012 – 2014**	**MSY (mt)**	**Total likelihood**
Base case	88.2	83.3	0.08	806.5	654.47
Alternative removal scenarios (Section 6.1.1)					
High catch	99.9	94.9	0.08	907.3	654.73
Low catch	75.9	71.7	0.08	712.0	653.80
Unfished initial conditions	76.2	77.2	0.09	784.5	654.41
Alternative stock-recruitment (Section 6.1.2)					
$\boldsymbol{z_{frac}}$					
z_{frac} at 0.3	203.4	202.1	0.04	1185.3	659.12
z_{frac} at 0.4	134.3	129.8	0.05	911.1	657.54
z_{frac} at 0.5	104.7	99.7	0.07	826.6	655.95
z_{frac} at 0.7	77.8	74.2	0.09	813.7	653.19
z_{frac} at 0.8	70.6	68.2	0.10	833.7	652.44
z_{frac} at 0.9	65.7	64.1	0.10	863.8	652.06
Beverton-Holt					
h at 0.495 (equivalent to base case)	110.2	62.7	0.10	763.7	655.90
h at 0.4	147.8	90.5	0.07	745.3	658.85
h at 0.6	90.3	50.7	0.12	796.6	652.88
h estimated (0.890)	63.3	43.8	0.14	843.5	648.87
Sigma-R					
Sigma-R at 0.3	74.1	68.6	0.09	668.2	655.93
Alternative life history (Section 6.1.3)					
Natural mortality					
0.50M	95.9	80.6	0.13	727.9	651.28
0.75M	87.5	79.0	0.11	759.9	652.80
1.25M	104.3	104.9	0.05	985.0	656.04
Growth					
Fixed growth (Smith et al.	78.8	77.8	0.08	797.4	667.20
Maturity and fecundity					
Age of maturity at 12 years (M=0.0757)	93.1	59.2	0.10	758.8	655.29
Biennial reproductive cycle	199.8	202.7	0.04	1206.7	659.28
Age of maturity at 12 years and biennial reproductive cycle (M=0.0757)	134.8	97.7	0.08	773.8	657.83

Sensitivity run description	**S_0 (1000s of fish)**	**S_{2014} (1000s of fish)**	**1-SPR 2012 – 2014**	**MSY (mt)**	**Total likelihood**
Alternative data sources and weightings (Section 6.1.4)					
Include S6 as juvenile index	88.3	84.1	0.08	809.2	652.78
Max weighting factors					
Max weighting factor >1	88.2	90.3	0.08	791.8	1954.92
Max weighting factor >1 except S6 and F3	89.6	82.6	0.08	802.2	1467.91
Downweighting size composition data					
Downweight F1	75.4	73.5	0.09	708.0	248.29
Downweight F2	91.4	85.2	0.08	836.6	626.60
Downweight F3	88.2	82.1	0.08	NA	597.10
Downweight F8	88.1	83.2	0.08	812.3	654.16
Downweight S6	88.5	82.0	0.08	803.9	606.14
Upweight CAAL data					
Upweight CAAL data	87.9	82.5	0.08	797.9	851.46
Alternative selectivity assumptions (Section 6.1.5)					
Alternative time blocks	85.8	78.1	0.09	815.4	705.98
F3 size selectivity	88.1	83.1	0.08	797.0	777.70
F6 estimate selectivity	88.1	83.9	0.08	803.0	656.47
Alternative spline parametrization					
Last knot at 215 cm	87.7	82.7	0.08	801.5	654.55
Last knot at 235 cm	88.5	83.6	0.08	806.3	654.22

Table 7.1. Estimated reference points for the base case model.

	Estimate (95% CI)	Units
Virgin Conditions		
Number of mature female sharks (spawning abundance) (S_0)	88.2 (69.5 – 107.0)	1000s of sharks
Reproductive output	352.9 (278.0 – 427.8)	1000s of pups
Summary biomass at age-1+ (B_0)	28,096 (21,768 – 34,424)	Metric tons
Recruitment at age-0 (R_0)	77.1 (60.7 – 93.5)	1000s of sharks
MSY-based reference points		
MSY	806.5 (614.7 – 998.3)	Metric tons
Number of mature female sharks at MSY (spawning abundance) (S_{MSY})	43.5 (34.6 – 52.4)	1000s of sharks
Minimum stock size threshold (MSST) (1-M)* S_{MSY}	35.7 (28.4 – 43.0)	1000s of sharks
Reproductive output at MSY	174.0 (138.3 – 209.7)	1000s of pups
Fishing intensity at MSY (1-SPR_{MSY})	0.39 (0.37 – 0.40)	NA

Table 8.1. Summary of reference points and management quantities for the base case and three alternative states of nature. C_{2014} is the estimated fishery removals in metric tons in 2014. 1-SPR_{1214} is the average of the estimated fishing intensity (1-SPR) from 2012 through 2014. Key management quantities for the USA fishery management plan are in bold. Under the current USA fishery management plan, this stock is declared to be in an overfished state if S_{2014}/MSST is <1. Overfishing is considered to be occurring if (1-SPR_{1214})/(1-SPR_{MSY}) is >1.

	Base case	**Alternative reproductive biology (12-years median age-of maturity; biennial; M = 0.0757)**	**Alternative stock-recruitment (z_{frac} = 0.4)**	**Alternative stock-recruitment (z_{frac} = 0.8)**
MSY (t)	806.5	773.8	911.1	833.7
Number of mature female sharks at MSY (S_{MSY}) (1000s of sharks)	43.5	33.9	71.6	32.0
Number of mature female sharks under virgin conditions (S_0) (1000s of sharks)	88.2	67.4	134.3	70.6
Minimum stock size threshold (MSST) (1-M)*S_{MSY}	35.7	27.9	58.8	26.3
Fishing intensity at MSY (1-SPR_{MSY})	0.39	0.39	0.34	0.45
C_{2014}/MSY	0.20	0.21	0.17	0.19
S_{2014}/S_{MSY}	1.91	1.44	1.81	2.13
S_{2014}/S_0	0.94	0.72	0.97	0.97
S_{2014}/MSST	2.33	1.75	2.21	2.59
(1-SPR_{1214})/(1-SPR_{MSY})	0.21	0.20	0.16	0.21

Table 9.1. Decision table of 10 year projections for three alternative states of nature based on two major axes of uncertainty: 1) reproductive biology and 2) stock-recruitment relationship; and three future catch scenarios: 1) average catch for 2012 – 2014; 2) 2 * average catch for 2012 – 2014; and 3) total annual catch of USA swordfish/shark drift gillnet and recreational fishery (i.e., F1, F2, F4, and F5) at the 340 t PFMC harvest guideline and rest of fisheries at average catch of 2012 – 2014. Note that the total removals shown for scenario 1 and 2 are approximate (±4 t) because catches by USA recreational fishery (F4 and F5) are in numbers of fish and conversion to catch in weight depends on the estimated growth for each model.

			Base model		**Alternative reproductive biology (12-years median age-of maturity; biennial; M = 0.0757)**		**Alternative stock-recruitment (z_{frac} = 0.4)**		**Alternative stock-recruitment (z_{frac} = 0.8)**	
Forecast catch scenario (see legend)	Year	Total removals (t)	Number of mature females (1000s of fish)	Depletion	Number of mature females (1000s of fish)	Depletion	Number of mature females (1000s of fish)	Depletion	Number of mature females (1000s of fish)	Depletion
Average catch 2012-14	2015	182.5	89.8	1.02	98.0	0.73	138.4	1.03	74.2	1.05
	2016	183.2	92.7	1.05	97.7	0.72	141.7	1.06	76.9	1.09
	2017	183.7	96.2	1.09	97.9	0.73	146.2	1.09	80.1	1.13
	2018	184.1	94.6	1.07	105.1	0.78	143.4	1.07	78.9	1.12
	2019	184.3	90.9	1.03	117.1	0.87	137.5	1.02	75.6	1.07
	2020	184.2	89.3	1.01	124.0	0.92	135.1	1.01	73.6	1.04
	2021	183.7	86.2	0.98	129.8	0.96	130.8	0.97	69.9	0.99
	2022	183.2	82.9	0.94	137.7	1.02	126.1	0.94	66.2	0.94
	2023	182.6	80.1	0.91	142.9	1.06	122.4	0.91	63.0	0.89
	2024	182.0	78.7	0.89	148.5	1.10	120.9	0.90	61.0	0.86
2X average catch 2012-14	2015	365.5	89.7	1.02	98.0	0.73	138.3	1.03	74.1	1.05
	2016	367.1	92.0	1.04	97.6	0.72	141.0	1.05	76.2	1.08
	2017	368.1	94.9	1.08	97.8	0.73	145.0	1.08	78.8	1.12
	2018	368.9	92.7	1.05	104.9	0.78	141.5	1.05	76.9	1.09
	2019	369.0	88.3	1.00	116.9	0.87	134.9	1.00	73.0	1.03
	2020	368.4	85.9	0.97	123.5	0.92	131.7	0.98	70.1	0.99
	2021	367.2	82.2	0.93	129.2	0.96	126.7	0.94	65.8	0.93
	2022	365.8	78.5	0.89	136.7	1.01	121.8	0.91	61.7	0.87
	2023	364.5	75.6	0.86	141.5	1.05	118.0	0.88	58.4	0.83
	2024	363.4	74.3	0.84	146.7	1.09	116.6	0.87	56.6	0.80
Harvest guideline 340 t for F1, F2, F4 & F5	2015	440.7	89.8	1.02	98.0	0.73	138.4	1.03	74.1	1.05
	2016	440.7	91.6	1.04	97.6	0.72	140.6	1.05	75.8	1.07
	2017	440.7	94.0	1.07	97.8	0.73	144.0	1.07	77.9	1.10
	2018	440.7	91.3	1.04	104.8	0.78	140.1	1.04	75.6	1.07
	2019	440.7	86.8	0.98	116.6	0.87	133.3	0.99	71.5	1.01
	2020	440.7	84.5	0.96	123.2	0.91	130.2	0.97	68.8	0.97
	2021	440.7	80.9	0.92	128.6	0.95	125.4	0.93	64.7	0.92
	2022	440.7	77.6	0.88	135.9	1.01	120.8	0.90	60.9	0.86
	2023	440.7	75.1	0.85	140.4	1.04	117.5	0.87	58.0	0.82
	2024	440.7	74.2	0.84	145.2	1.08	116.6	0.87	56.6	0.80

FIGURES

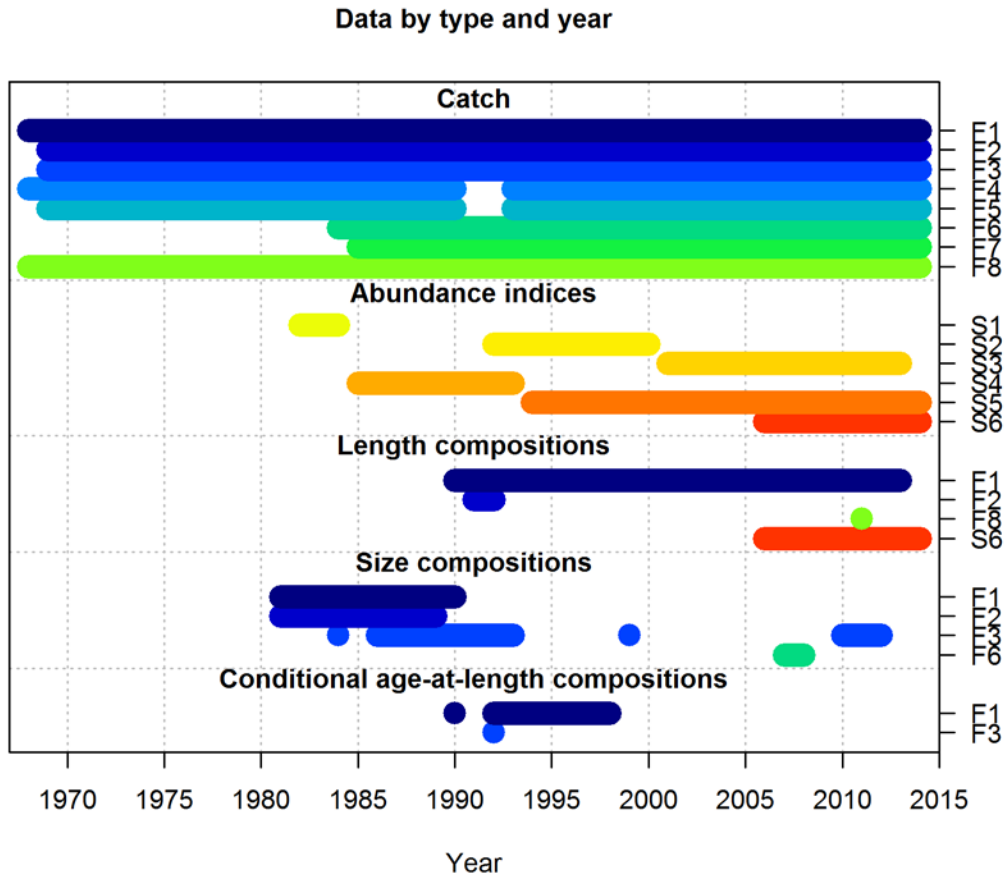


Figure 2.1. Summary of data used in the assessment. Description of fleets (F1 – F8) and abundance indices (S1 – S6) are found in Table 2.1.

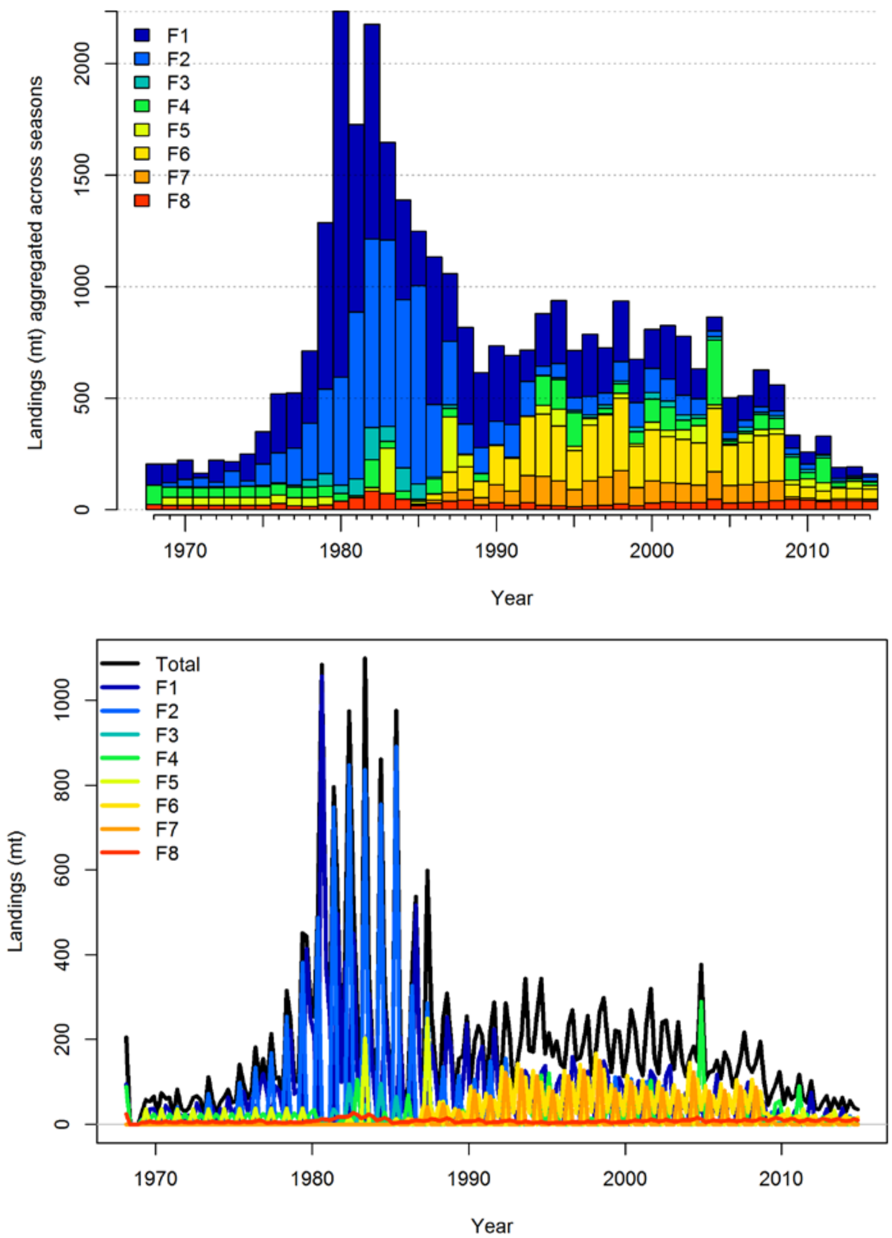


Figure 2.2. Estimated annual (upper) and seasonal (lower) common thresher shark removals by fleet. Description of fleets (F1 – F8) are found in Table 2.1. Note that removals in upper panel are stacked but not in lower panel.

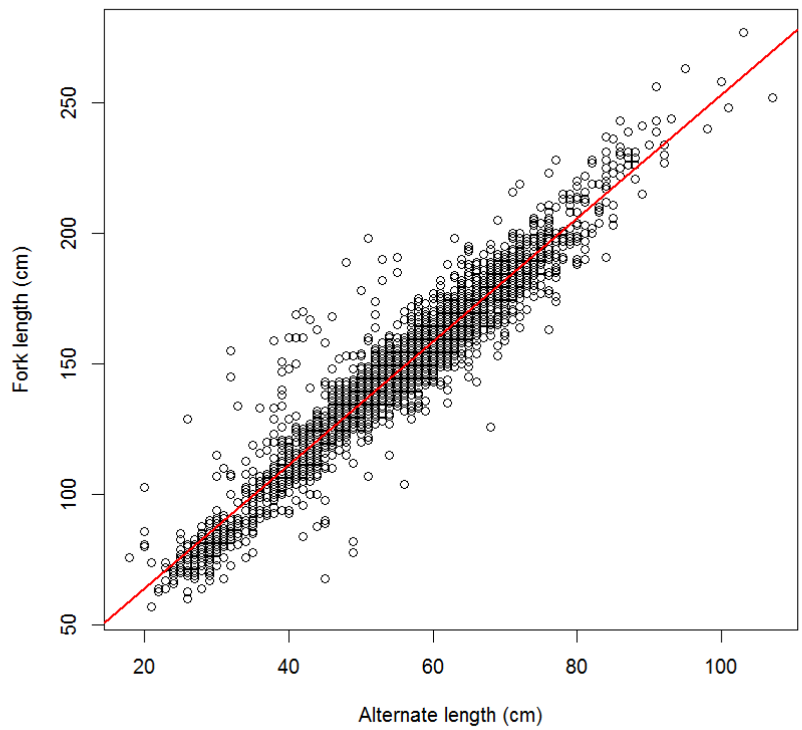


Figure 2.3. Estimated relationship between alternate and fork length for common thresher sharks along the USA West Coast. Fork length (cm) = 2.3627 × Alternate length (cm) + 16.82 (N = 3043 fish; adj. R^2 = 0.9165).

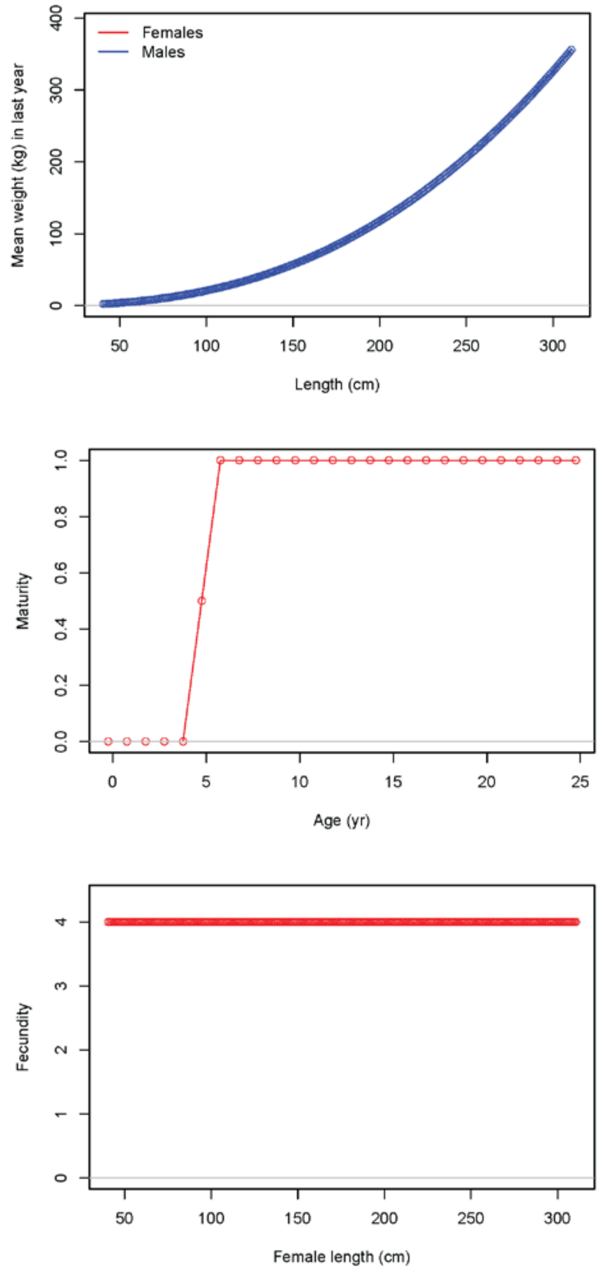


Figure 3.1. Fixed weight-at-length (upper), maturity-at-age (middle), and annual fecundity-at-length (lower) relationships used in the base case model. See Section 2.3 and 3.4.1.

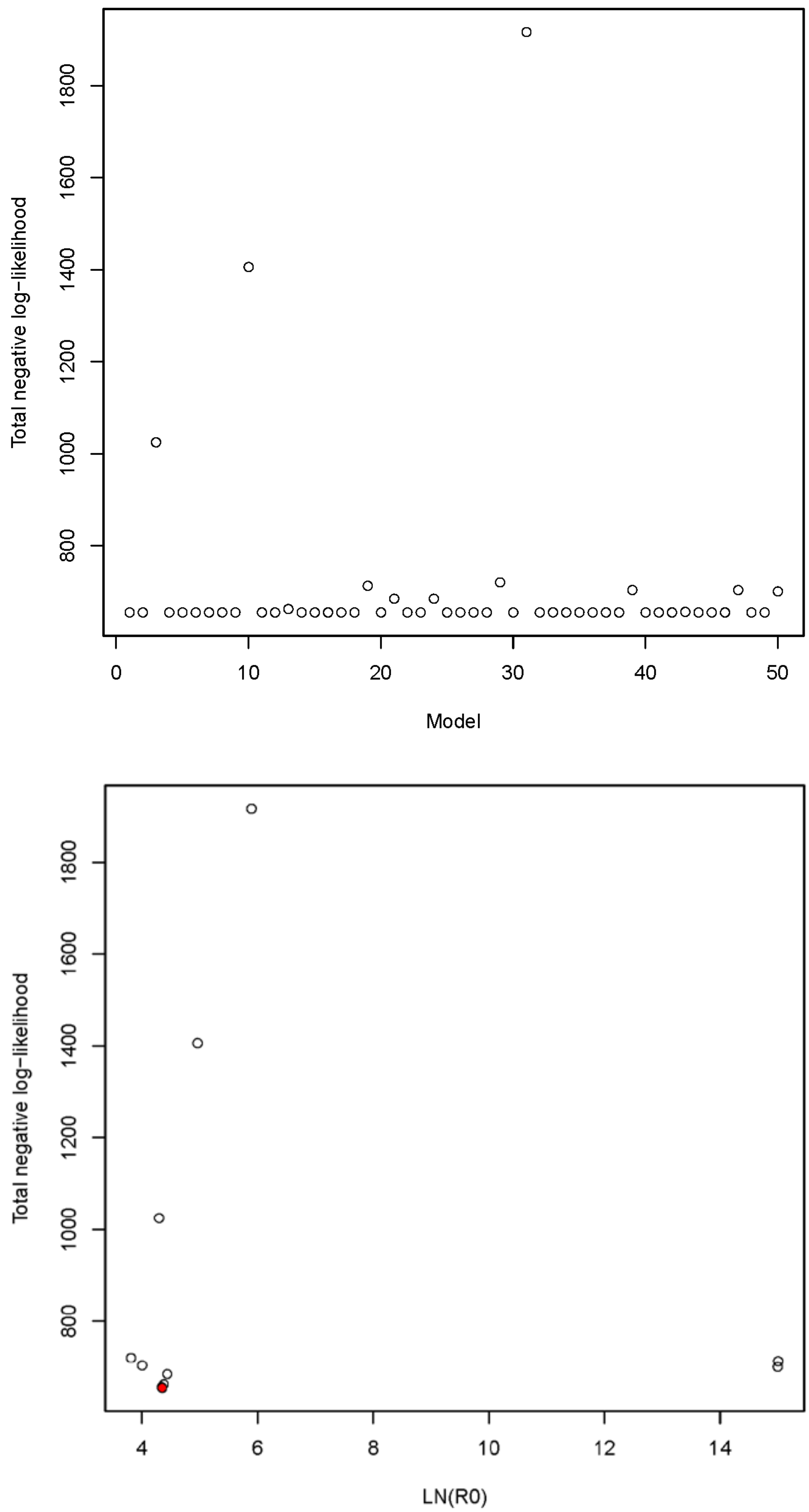


Figure 4.1. Convergence analysis of the base case model. Total negative log-likelihood of the base case model (Model 1) and 50 models using different phasing and initial parameters (upper); and estimated log virgin recruitment [LN(R0)], with the base case model in red (lower).

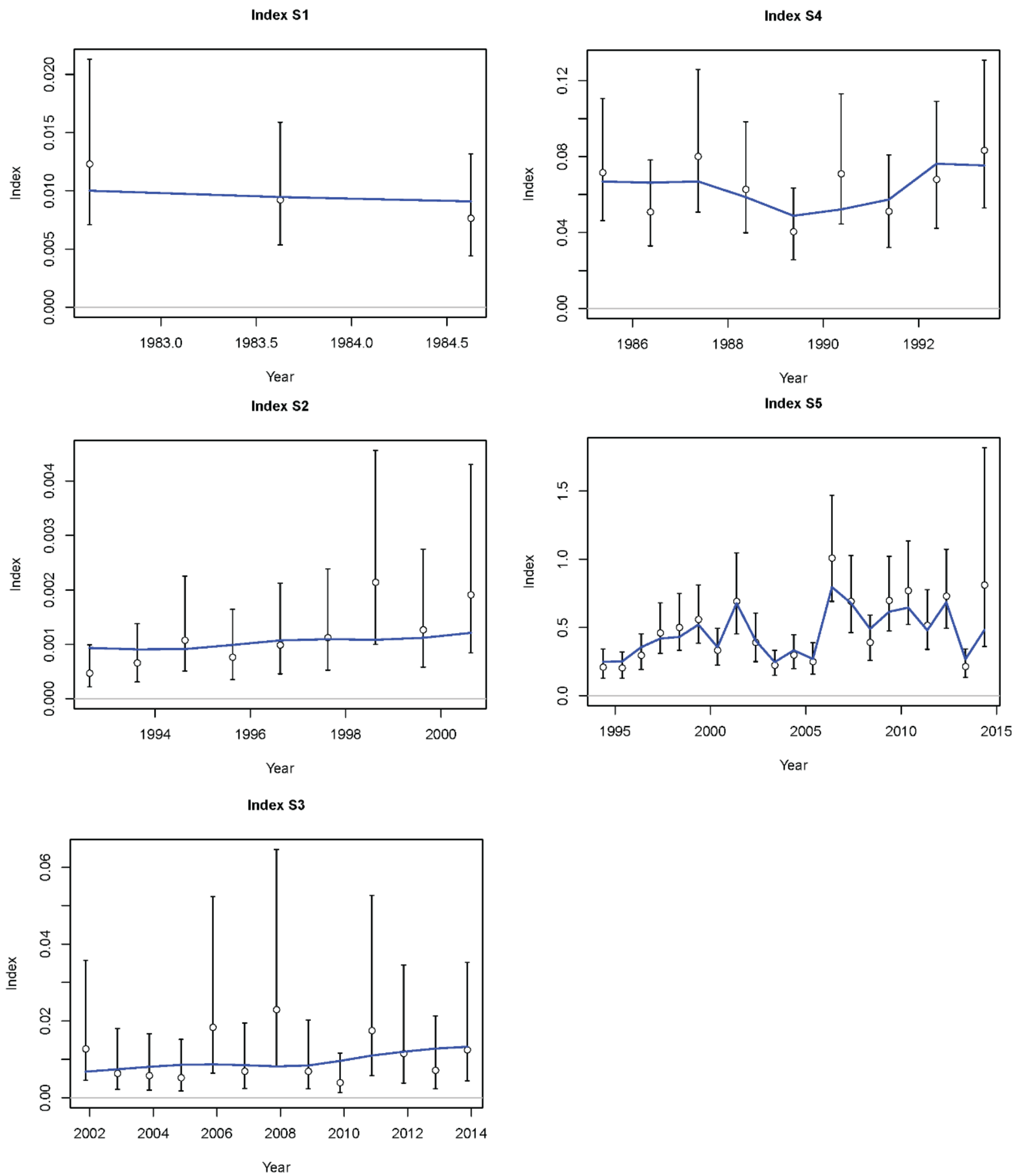


Figure 4.2. Observed (open circles) and expected (blue line) relative abundance of common thresher sharks from sub-adult/adult (S1, S2, and S3) and recruitment (S4 and S5) abundance indices in the base case model. Error bars indicate 95% confidence intervals.

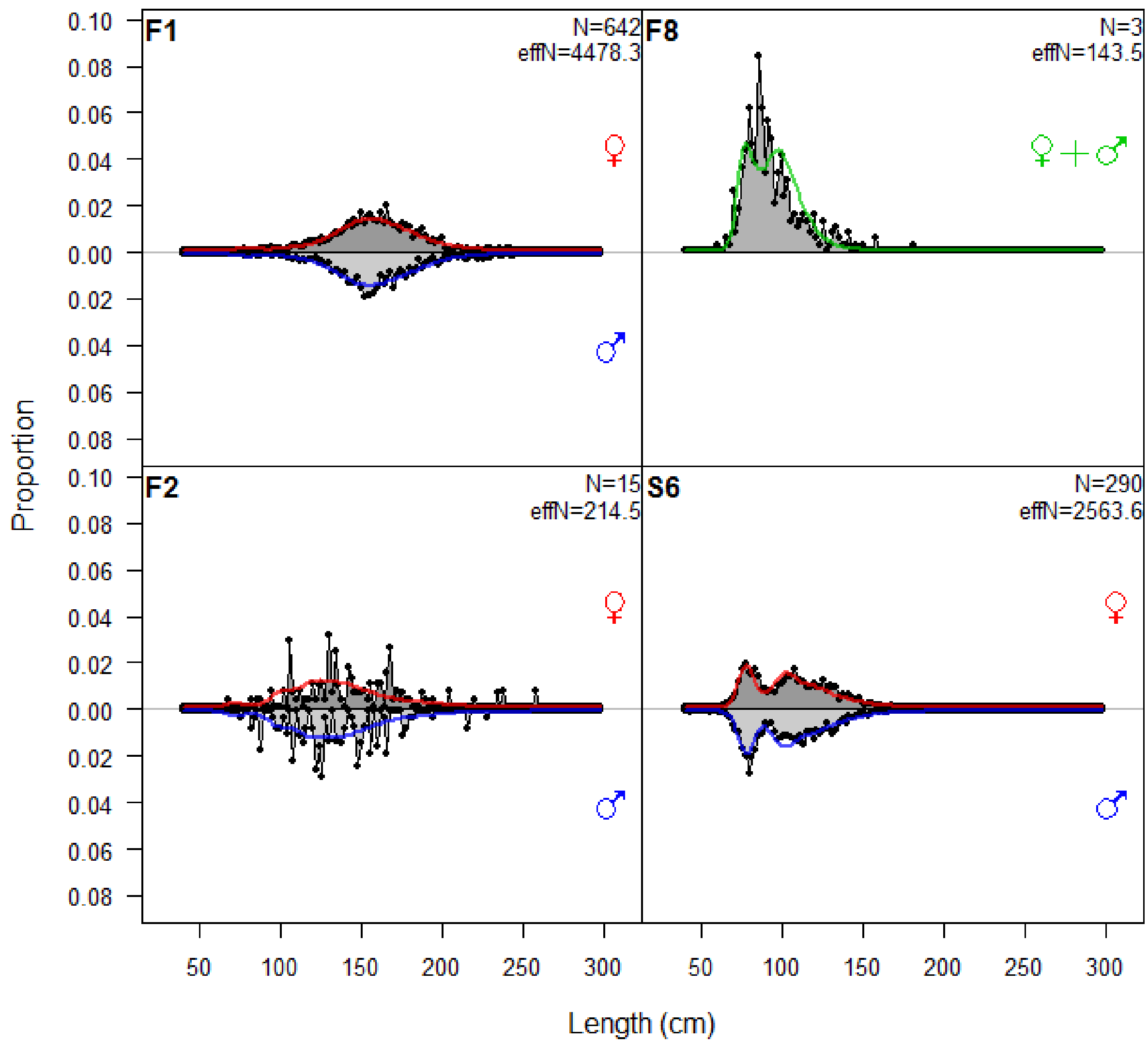


Figure 4.3. Observed (grey) and model predicted (red: female; blue: male; green: sex-combined) overall size compositions in 2 cm bins for the base case model. Size compositions for the MXART (F8) fleet were aggregated into a single year and input as a super year.

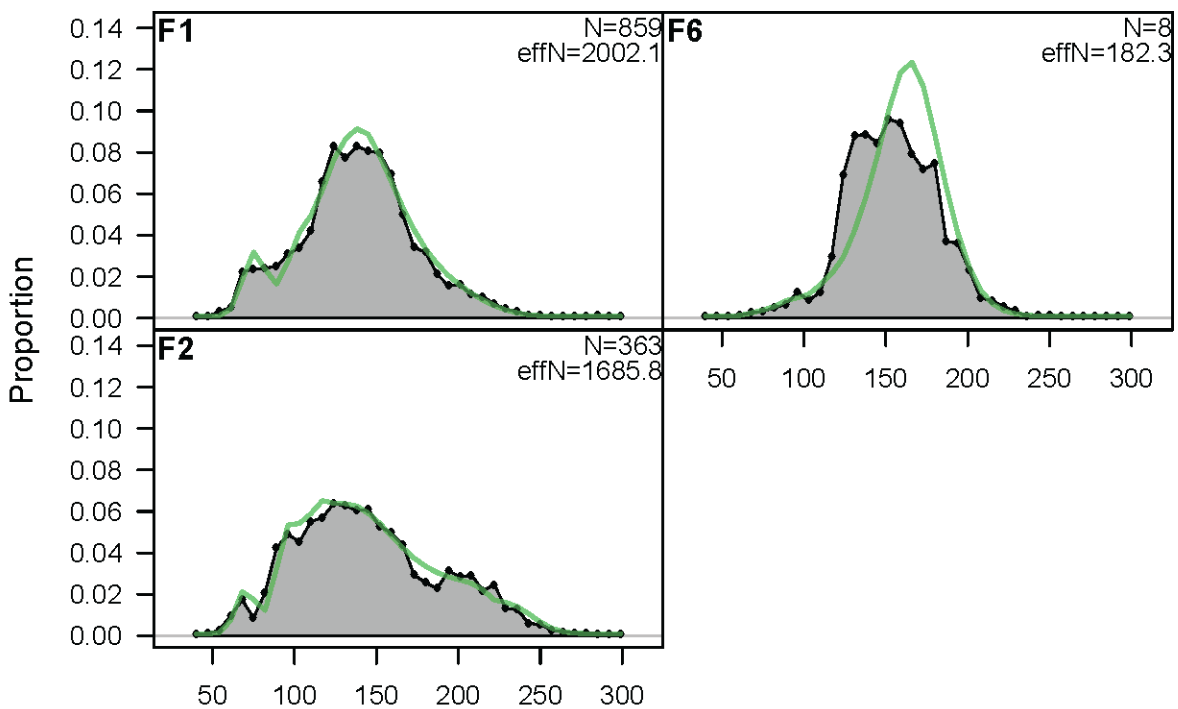
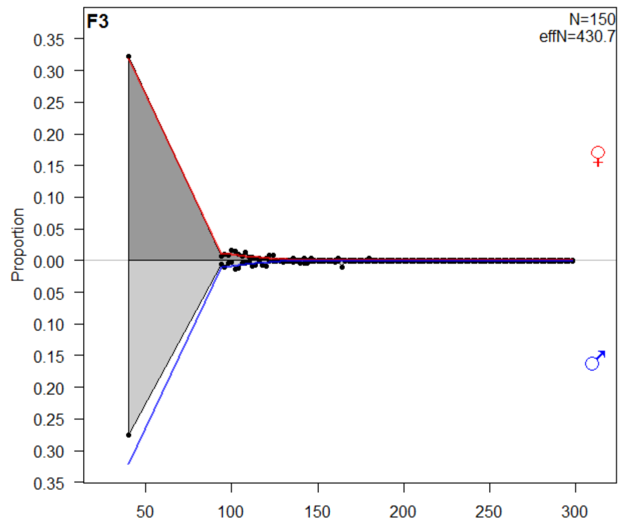


Figure 4.4. Observed (grey) and model predicted (green: sex-combined) overall size compositions in 7 cm bins for the base case model. Size compositions for the MXDGNLL (F6) fleet were not fit in the base case model but selectivity for F6 was assumed to be the same as the USDGN (F1) fleet.



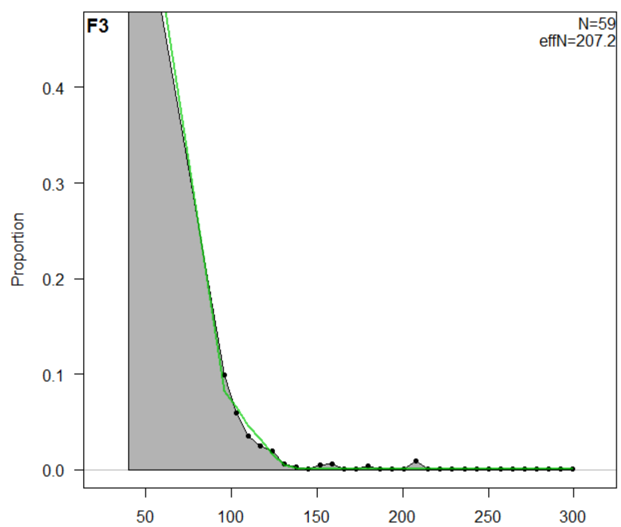


Figure 4.5. Observed (grey) and model predicted (red: female; blue: male; green: sex-combined) overall size compositions in 2 (upper) and 7 (lower) cm bins for the base case model. Size bins that approximated age-0 sized fish were aggregated into a single bin for the USSN (F3) fleet.

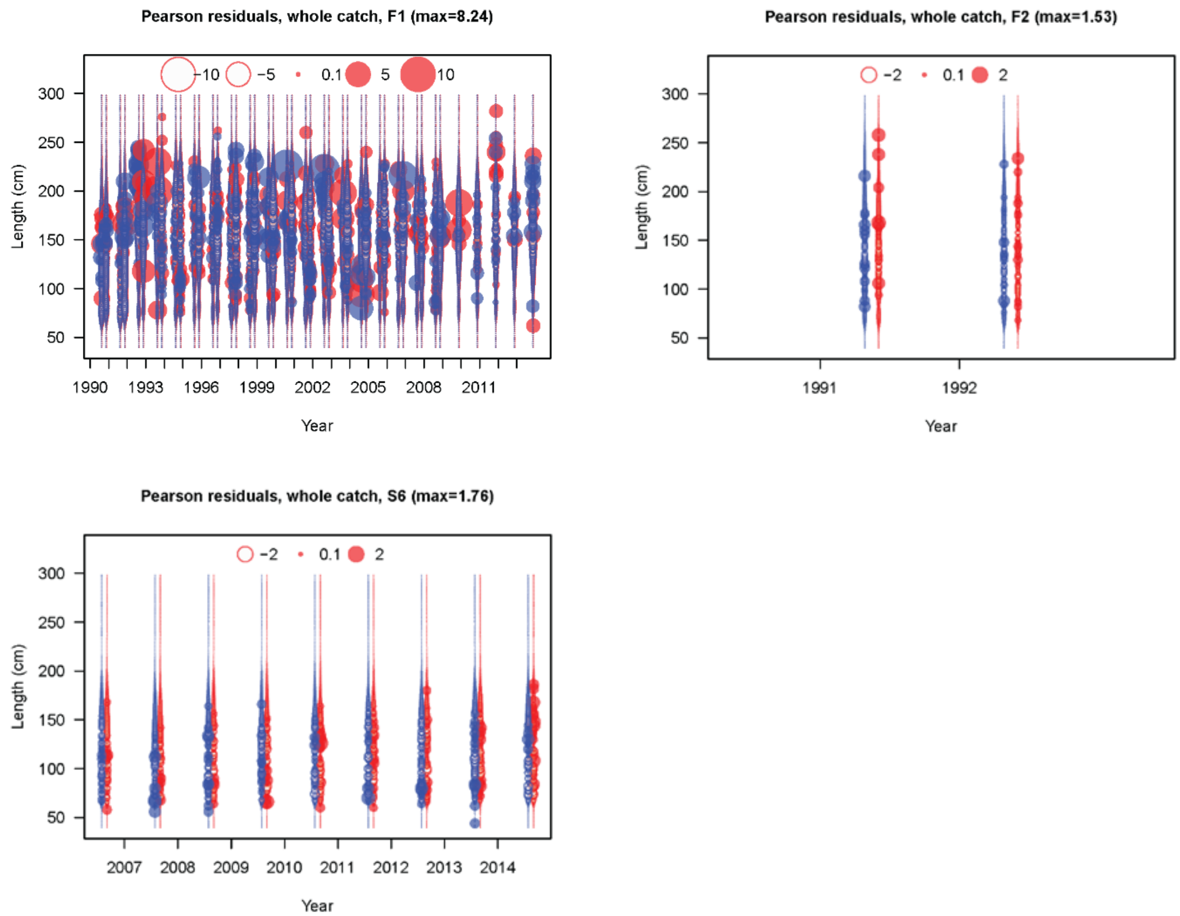


Figure 4.6. Pearson residuals of model fit to size composition data in 2 cm bins for the base case model. Filled and open circles represent observations (i.e., proportions at size) that are larger and smaller than model predictions, respectively. Blue and red circles represent male and female samples respectively. Area of circles are proportional to absolute values of residuals. Residuals of F8 are not shown here because its size composition data were input as a super year (i.e., a single year of observation) and residuals are better seen in Fig. 4.3.

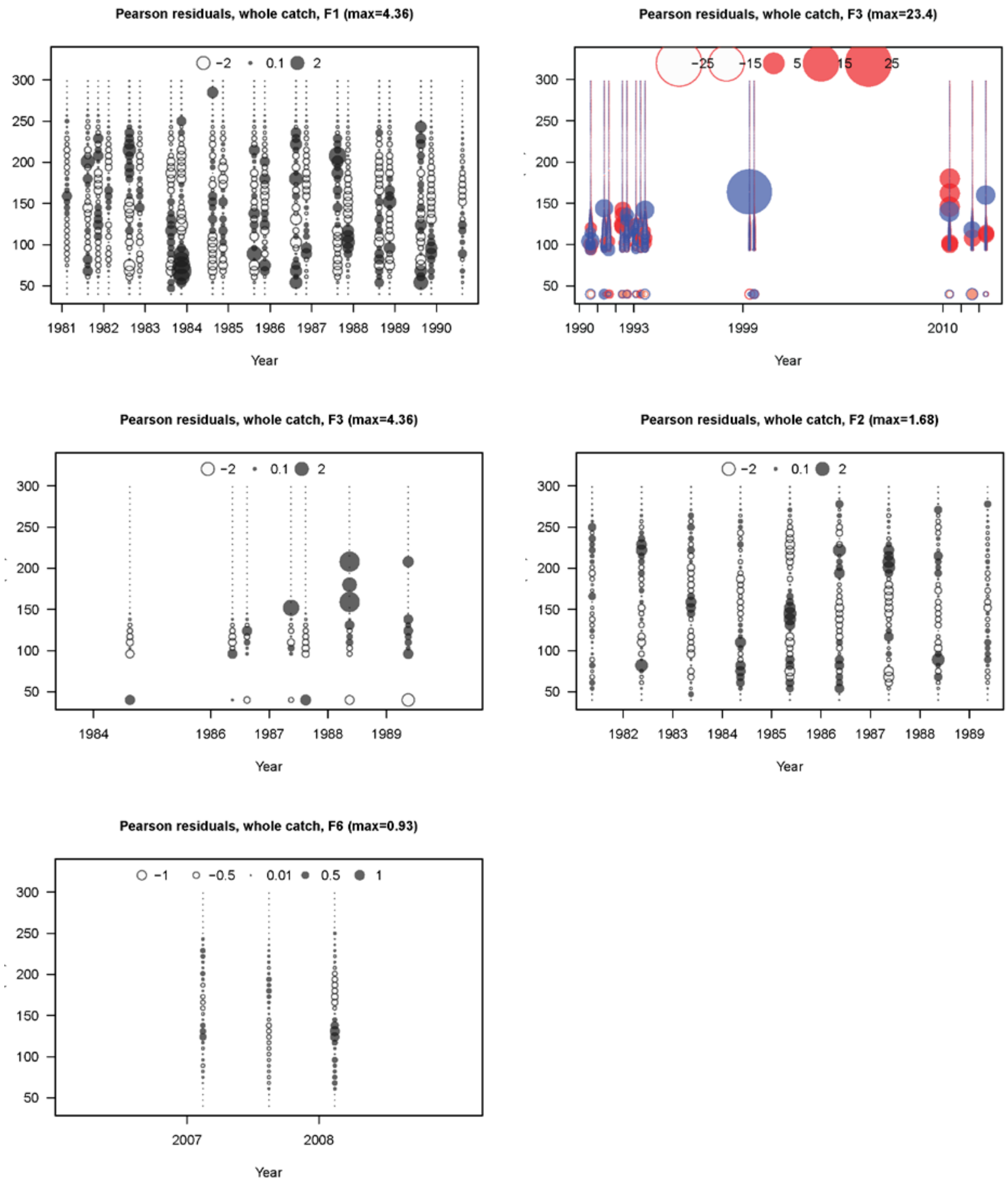


Figure 4.7. Pearson residuals of model fit to size composition data in 7 cm bins (left panels) and age-0 aggregated 2 cm (upper right; blue: male; red: female) and 7 cm bins (middle right) for the base case model. Filled and open circles represent observations that are larger and smaller than model predictions, respectively. Area of circles are proportional to absolute values of residuals.

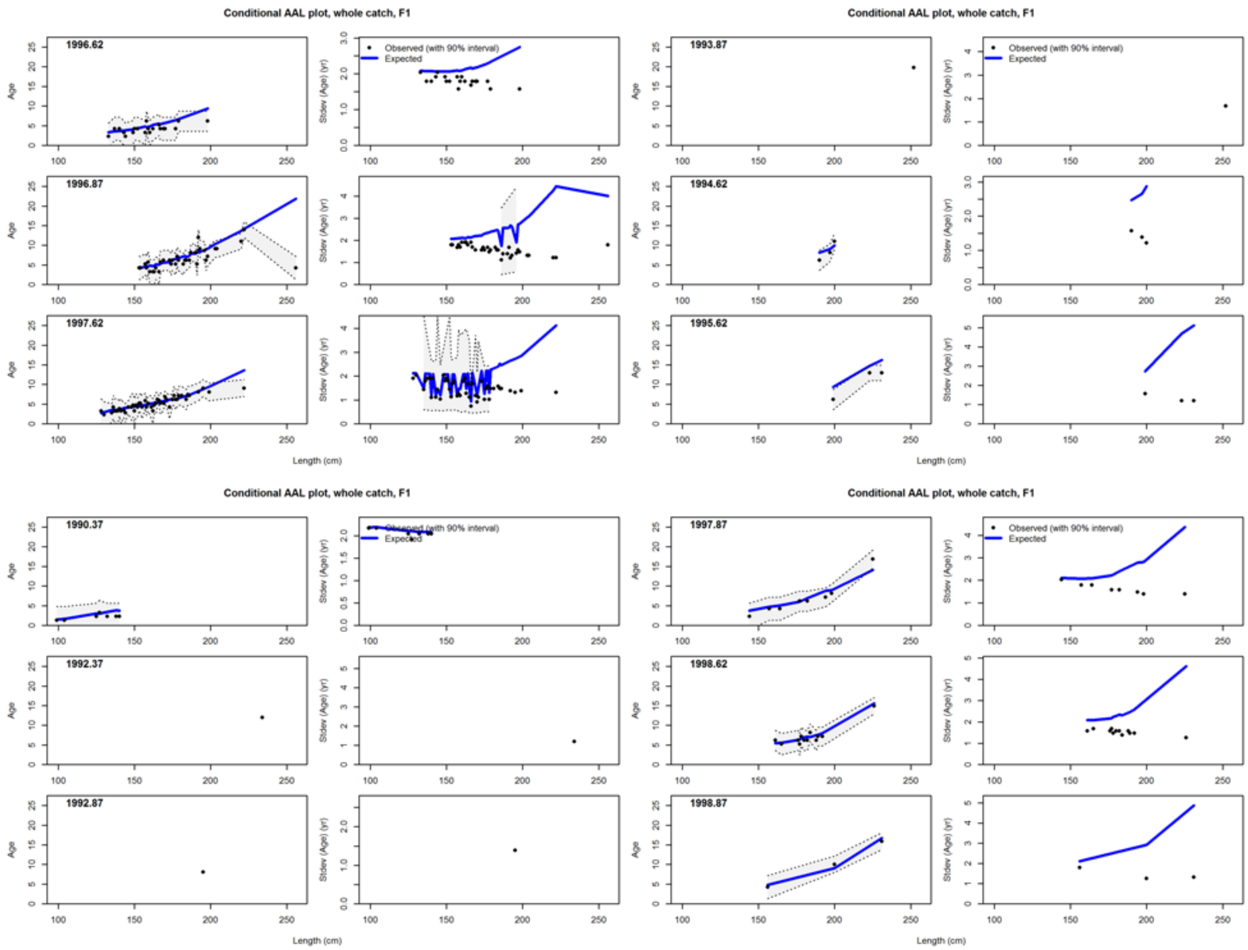


Figure 4.8. Base case model fit to conditional-age-at-length data from the USDGN (F1) fleet.

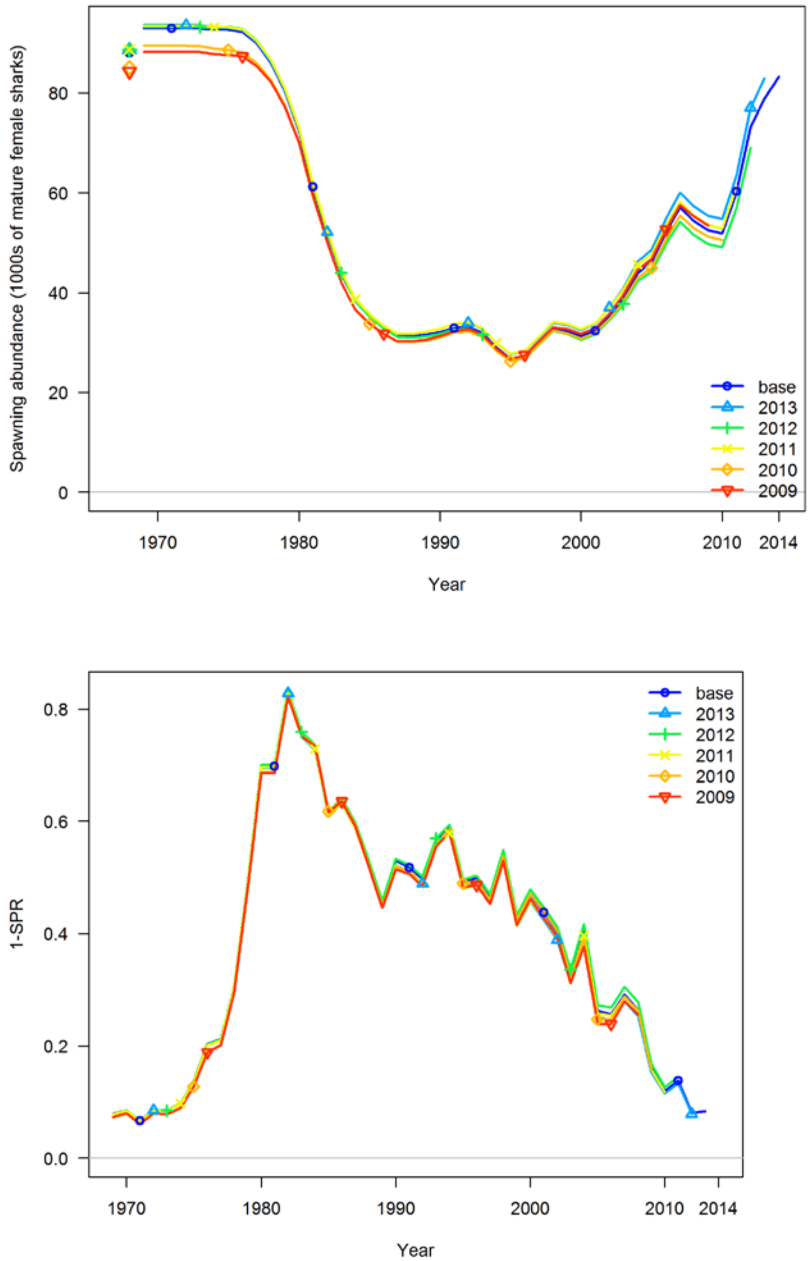


Figure 4.9. Retrospective analysis of base case model. Estimated spawning abundance (1000s of mature female sharks) (upper) and fishing intensity (1-SPR) (lower) with successive elimination of 1 – 5 years of terminal year data.

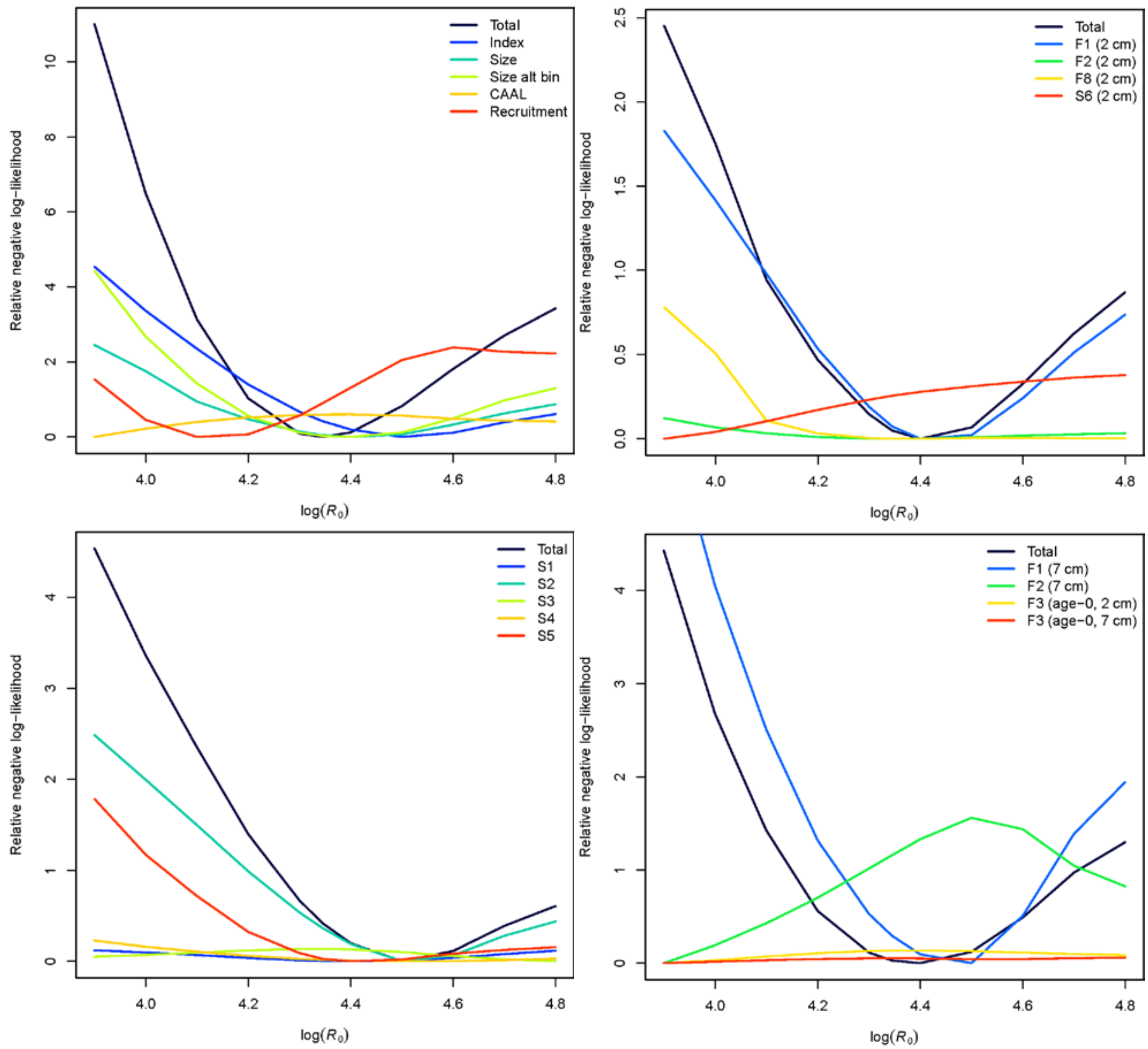


Figure 4.10. Likelihood profiles with respect to virgin recruitment [log(R_0)] of the main data components (upper left), abundance indices (lower left), main sex-specific size compositions using 2 cm bins (upper right), and size compositions using alternative binning structures (Section 2.1.4), of the base case model.

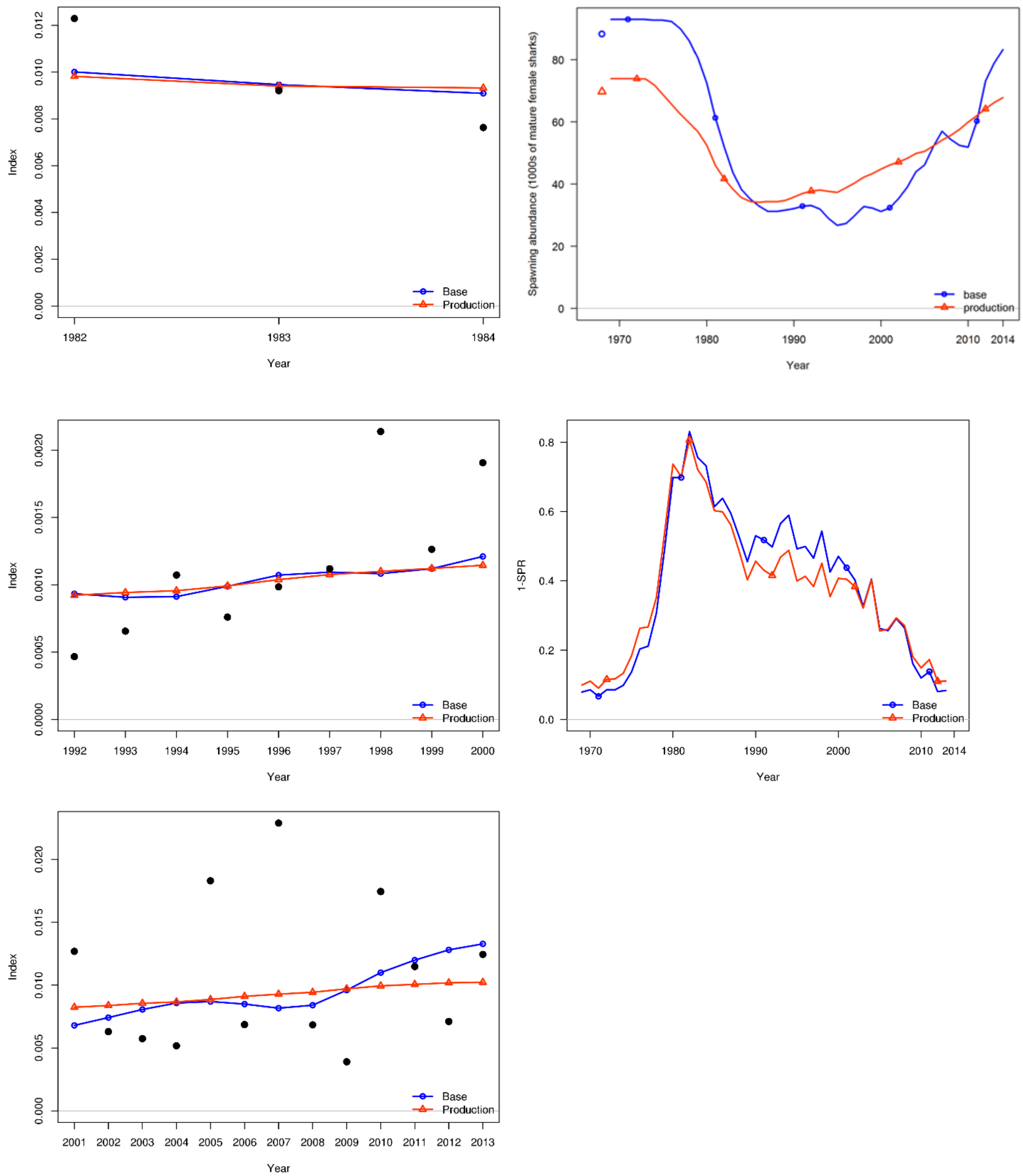


Figure 4.11. Model fits to sub-adult/adult abundance indices (S1: upper left; S2: middle left; S3: lower left), estimated female spawning abundance (upper right) (1000s of mature female sharks), and fishing intensity (middle right) (1 – SPR) of the base case model (blue) and an age-structured production model (red) with similar model specifications to the base case model but fitting only to the catch and sub-adult/adult abundance indices.

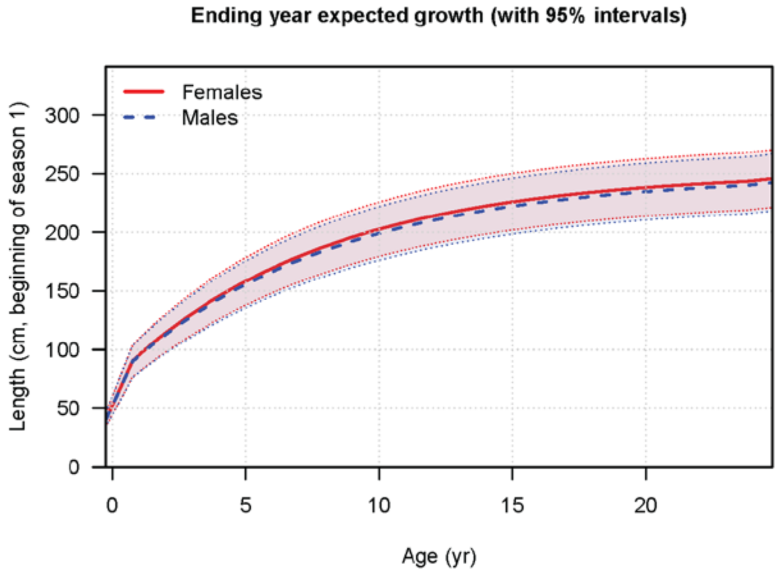


Figure 5.1. Estimated growth curve of female (solid red line) and male (dashed blue line) common thresher sharks. Shaded areas represent the 95% confidence intervals. The coefficient of variation of length at age were fixed at birth (0.08) and L_{inf} (0.05), and linearly interpolated between those two points.

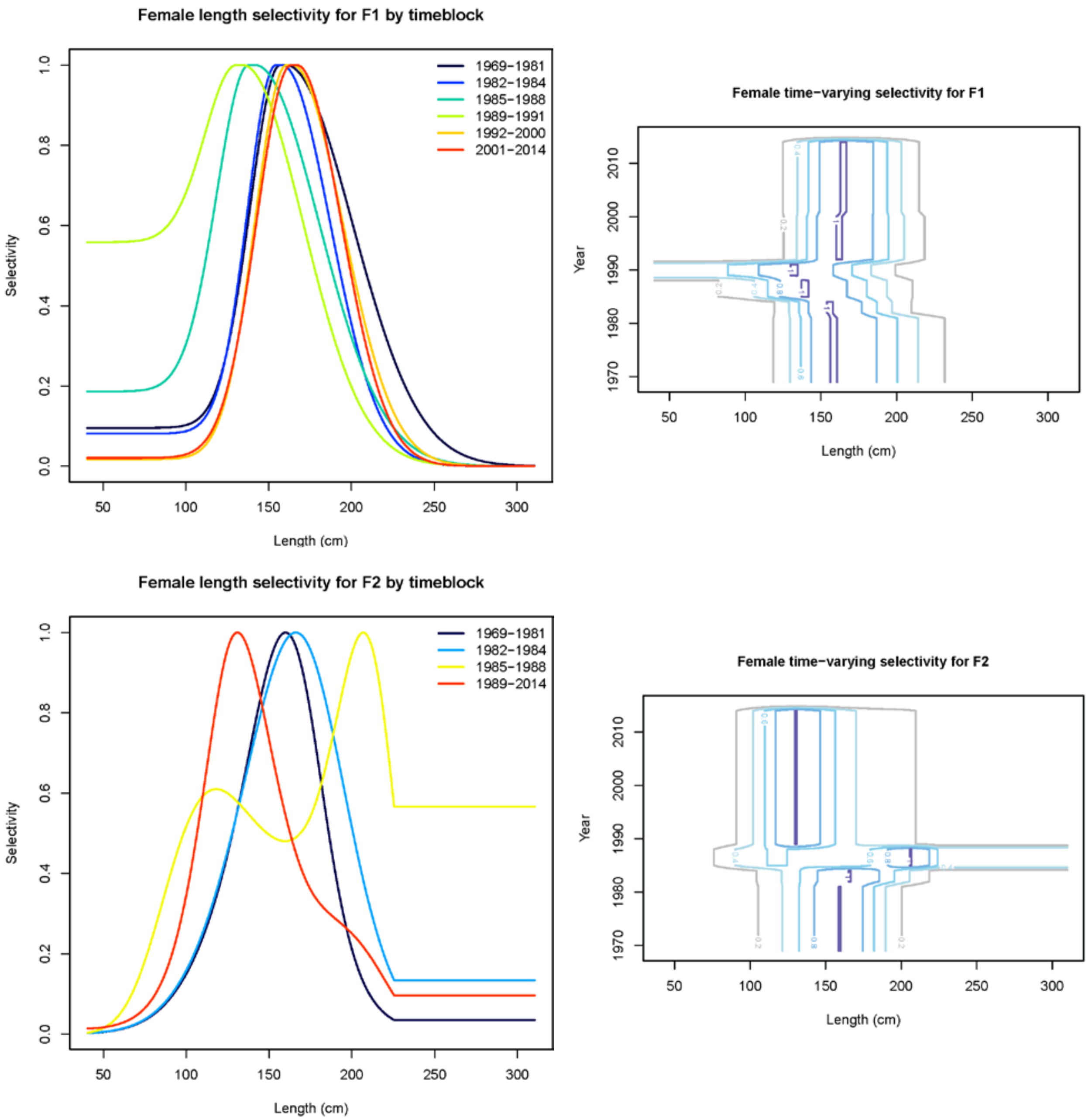


Figure 5.2. Estimated length selectivities of USDGN (F1) and USDGNs2 (F2) fleets by time period (left panels) and time-varying contour plots (right panels) in the base case model. Male selectivity was assumed to be the same as female selectivity for all fleets. Selectivities of F4, F6, S1, S2, and S3 were mirrored to F1, while F5 and F7 were mirrored to F2.

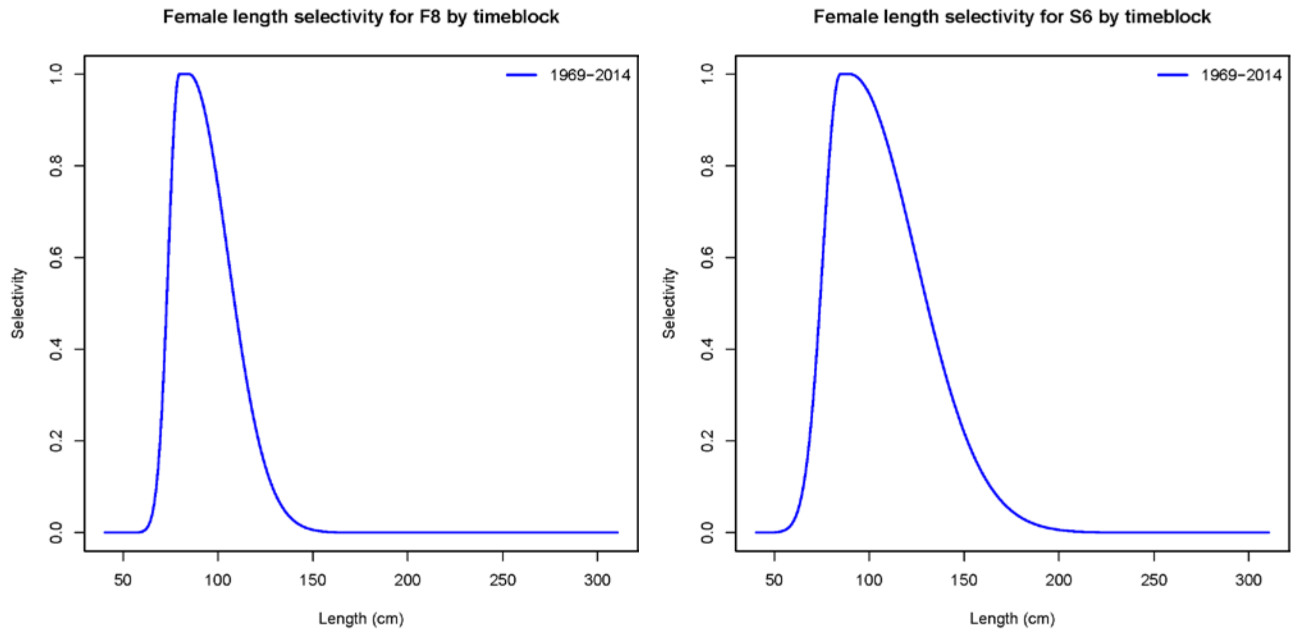


Figure 5.3. Estimated length selectivities of the MXART (F8) fleet and USJUV0614 (S6) survey in the base case model. Male selectivity was assumed to be the same as female selectivity for all fleets.

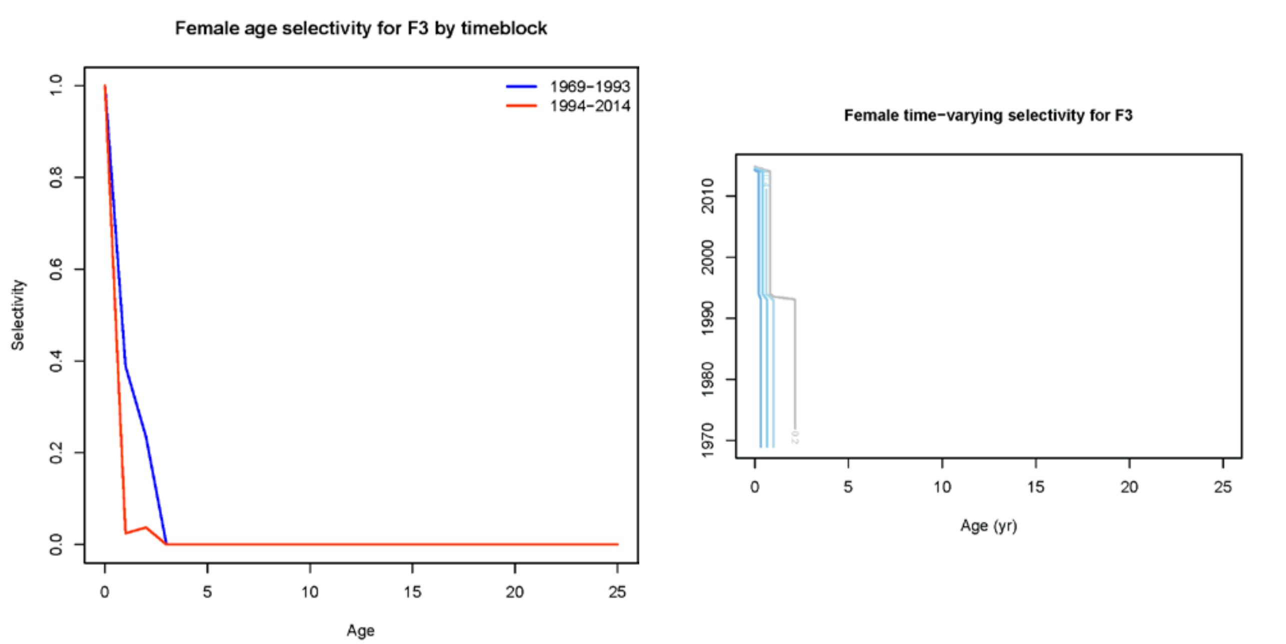


Figure 5.4. Estimated age selectivities of the USSN (F3) fleet by time period (left panels) and time-varying contour plots (right panels) in the base case model. Male selectivity was assumed to be the same as female selectivity for all fleets. Selectivities of S4 and S5 were mirrored to F3.

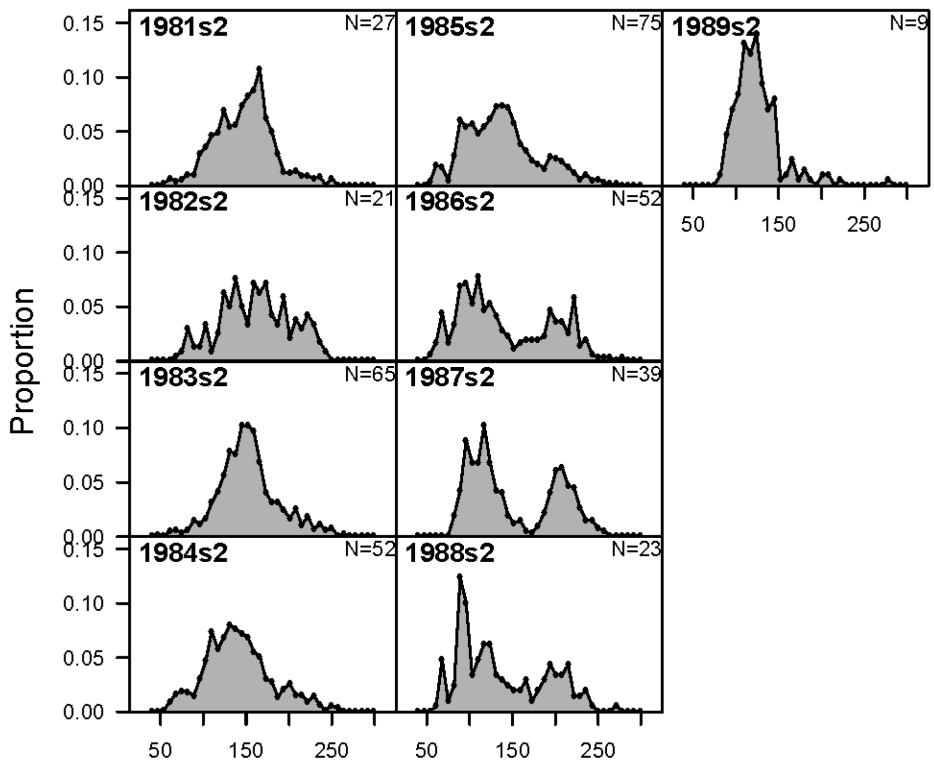


Figure 5.5. Size composition data of the USDGNs2 (F2) fleet during 1981 – 1989. Note the large number of large fish >200 cm between 1985 and 1988.

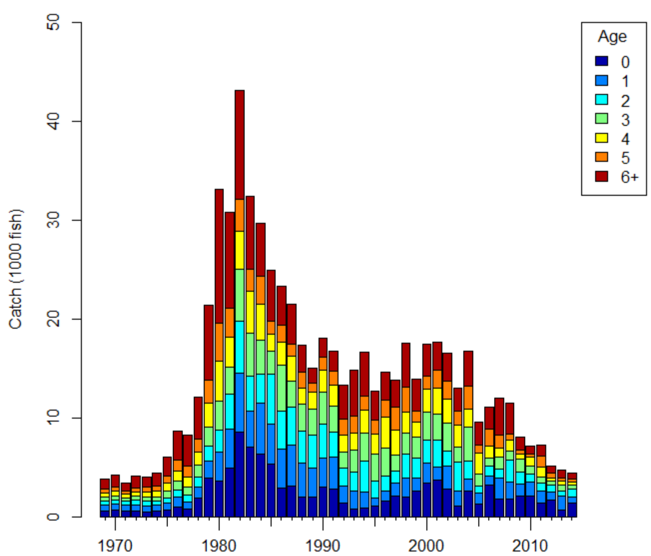


Figure 5.6. Historical catch-at-age (1000s of fish) estimated by the base case model. The base case model was parameterized with 26 age classes (age-0 to 25) but ages-6+ (100% maturity) were summed for clarity.

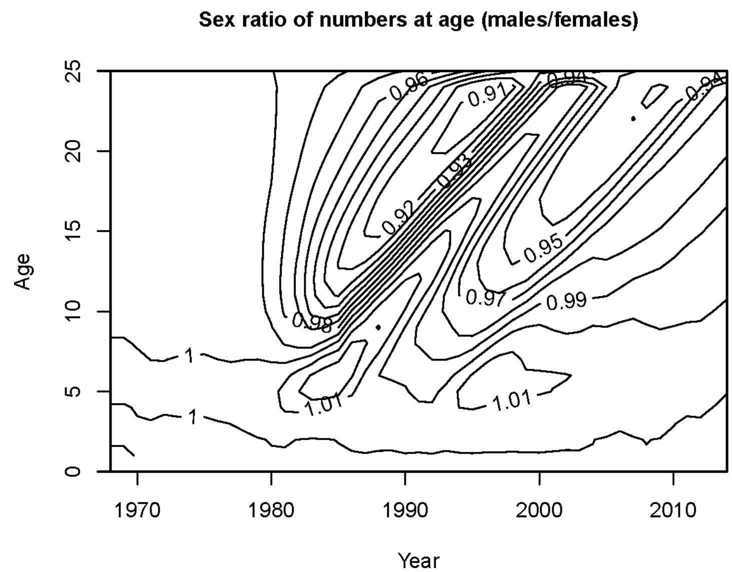


Figure 5.7. Sex ratio (male/female) of numbers at age estimated in the base case model.

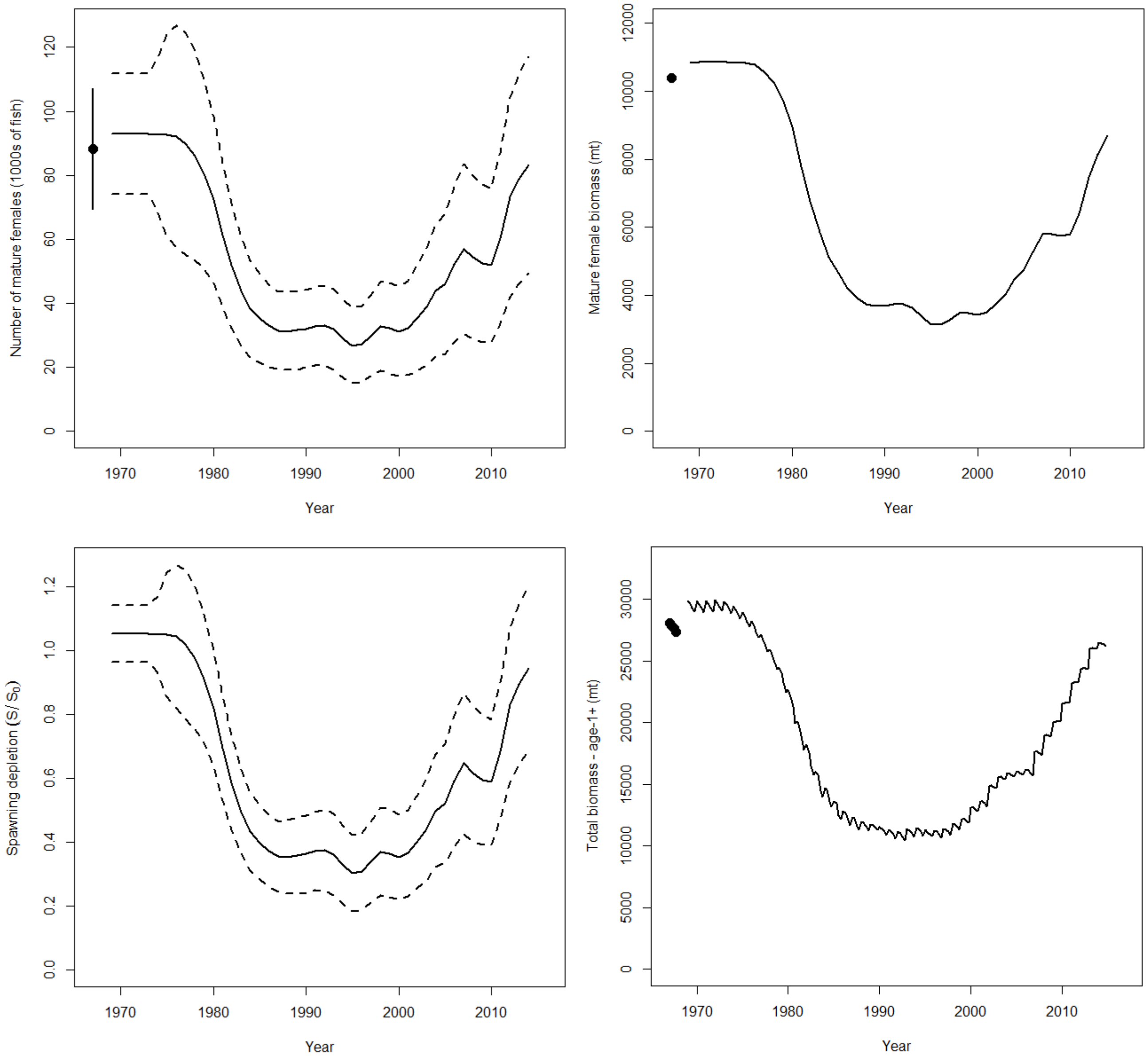


Figure 5.8. Estimated number of mature female sharks in Q2 (upper left); spawning depletion based on number of mature female sharks (S/S_0) (lower left); biomass of mature female sharks (upper right); and seasonal total biomass (age-1+) (lower right). Dashed lines indicate 95% confidence intervals; and closed circles and error bars indicate estimated quantities and 95% confidence intervals under virgin conditions, respectively. Estimated virgin number of mature female sharks (S_0) is 88,220 fish. Spawning output in number of pups is 4 * number of mature females.

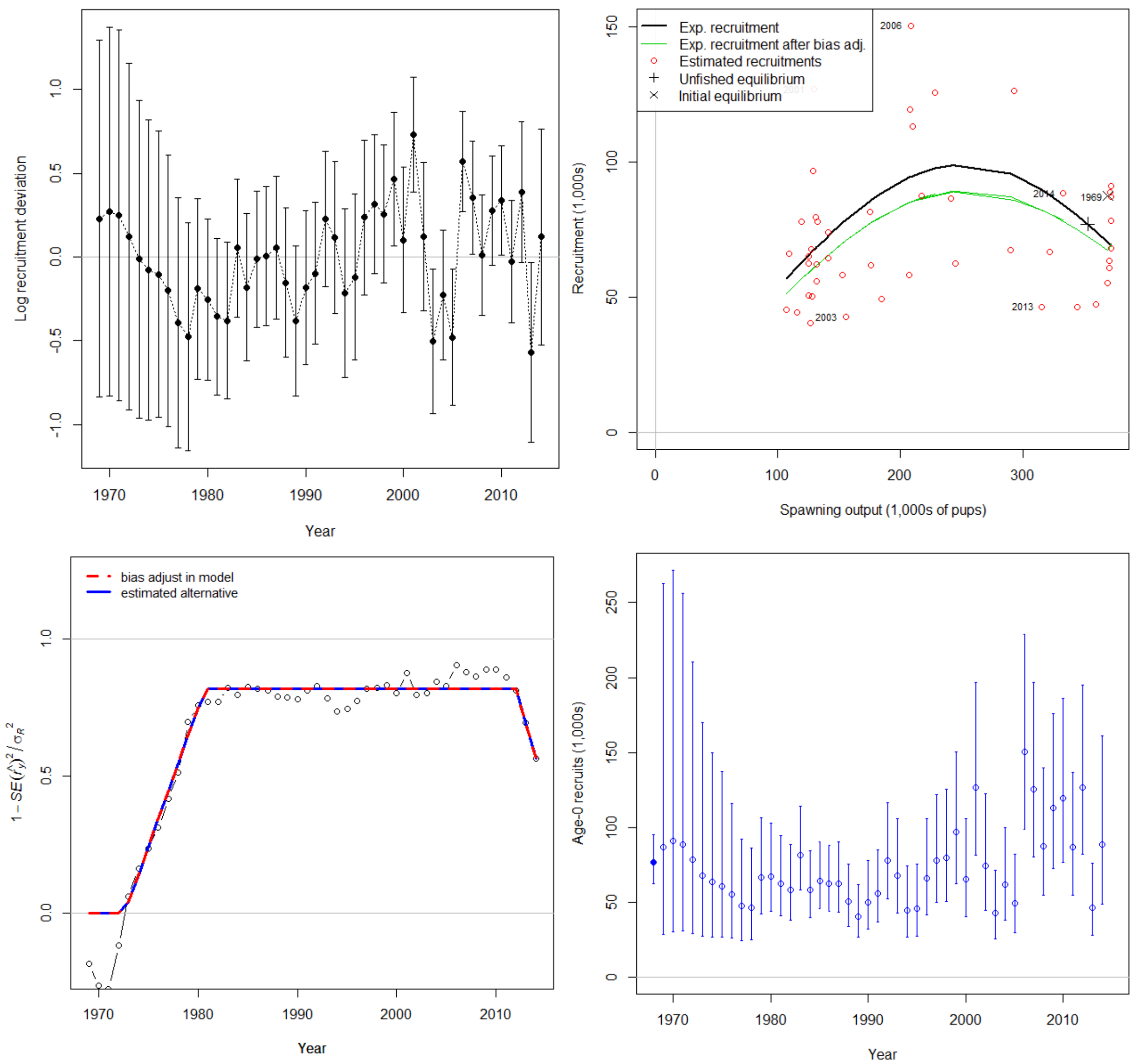


Figure 5.9. Estimated log-recruitment deviations (upper left), recruitment bias adjustment (lower left), spawner-recruit relationship (upper right), and recruitment time series (lower right) from the base case model.

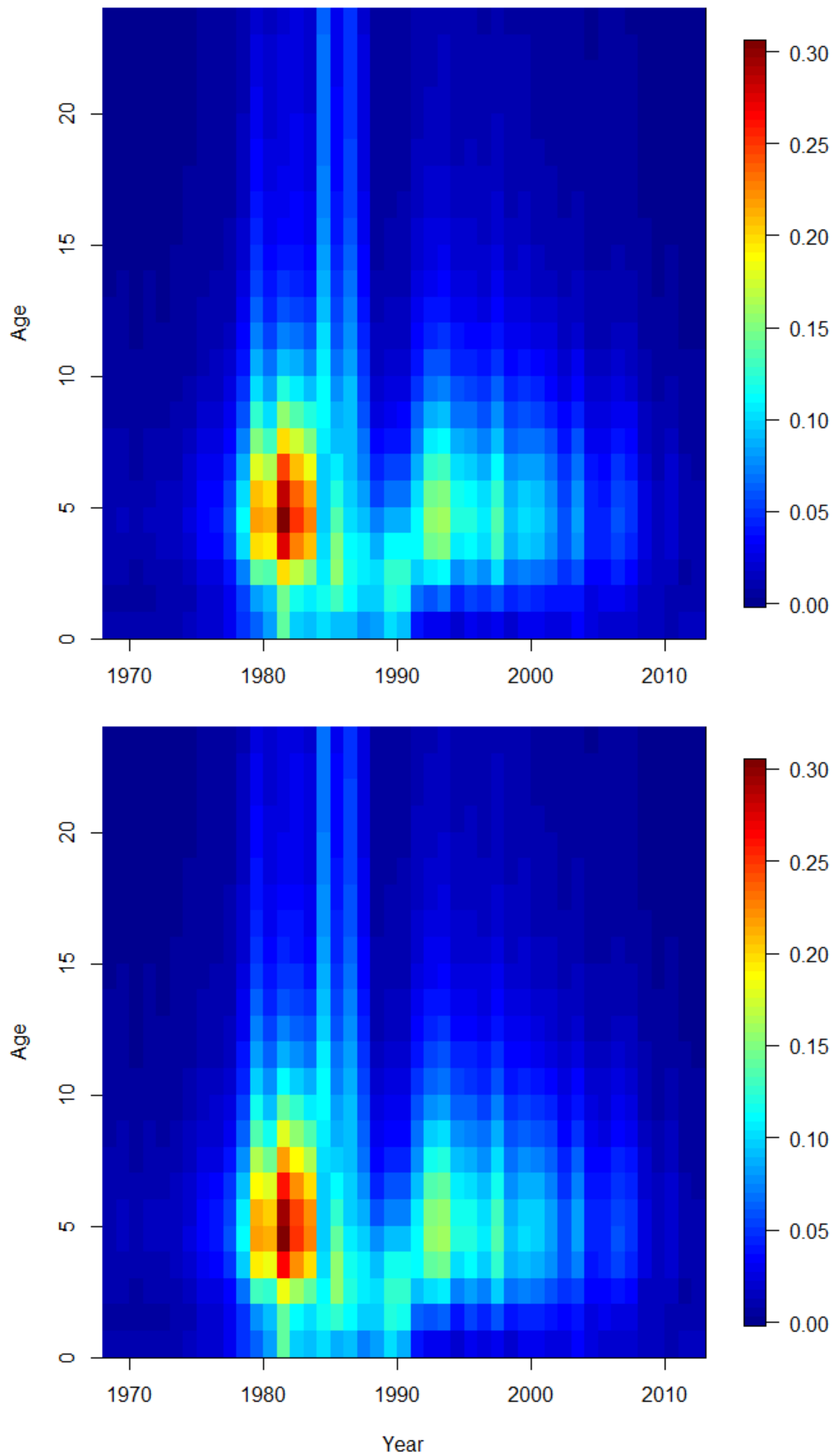


Figure 5.10. Estimated fishing mortality at age (F-at-age) for female (upper) and male (lower) common thresher sharks from the base case model.

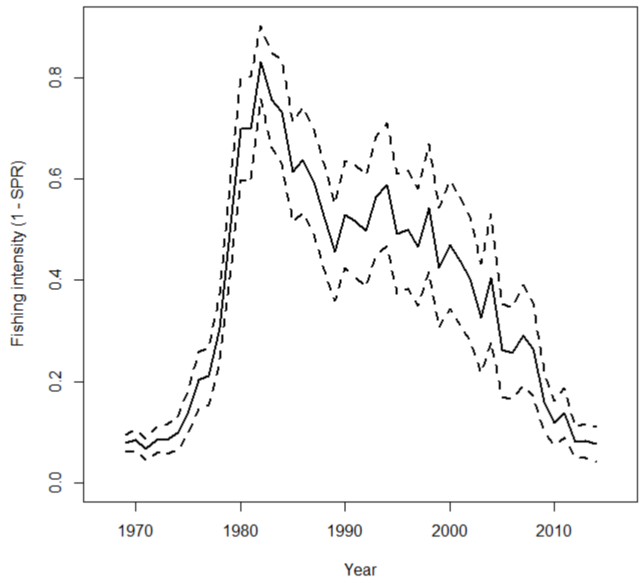


Figure 5.11. Estimated fishing intensity (1-SPR) from the base case model. Black line indicates the maximum likelihood estimate while dashed lines indicate 95% confidence intervals.

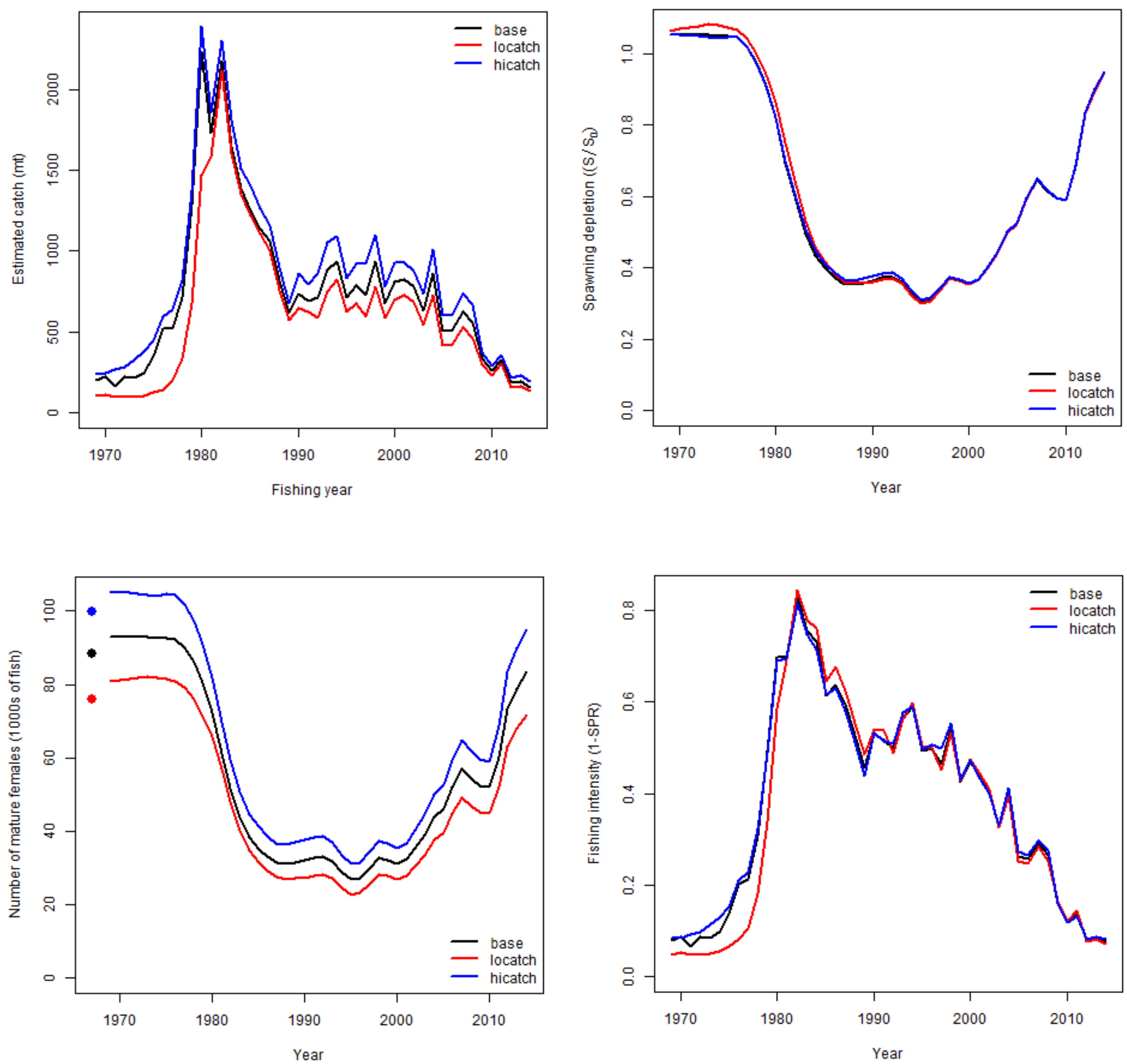


Figure 6.1. Estimated catch in metric tons (mt) (upper left), number of mature female sharks (lower left), spawning depletion (upper right), and fishing intensity (1-SPR) (lower right) for the base case model (black) and sensitivity runs using high (blue) and low (red) catch scenarios.

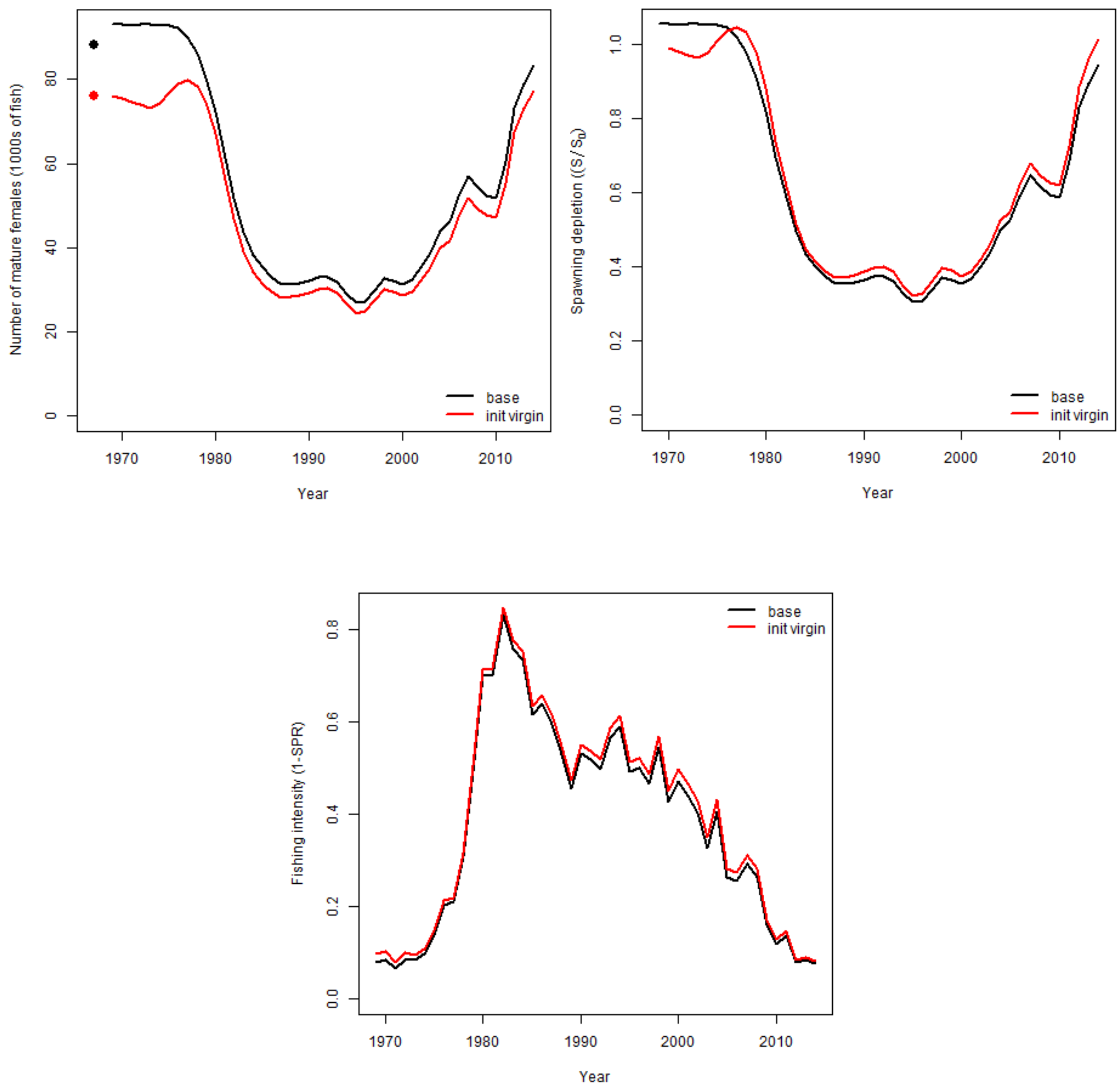


Figure 6.2. Estimated number of mature females (upper left), spawning depletion (upper right), and fishing intensity (1-SPR) (lower) for the base case model (black) and a sensitivity run assuming that the model started under virgin conditions (red).

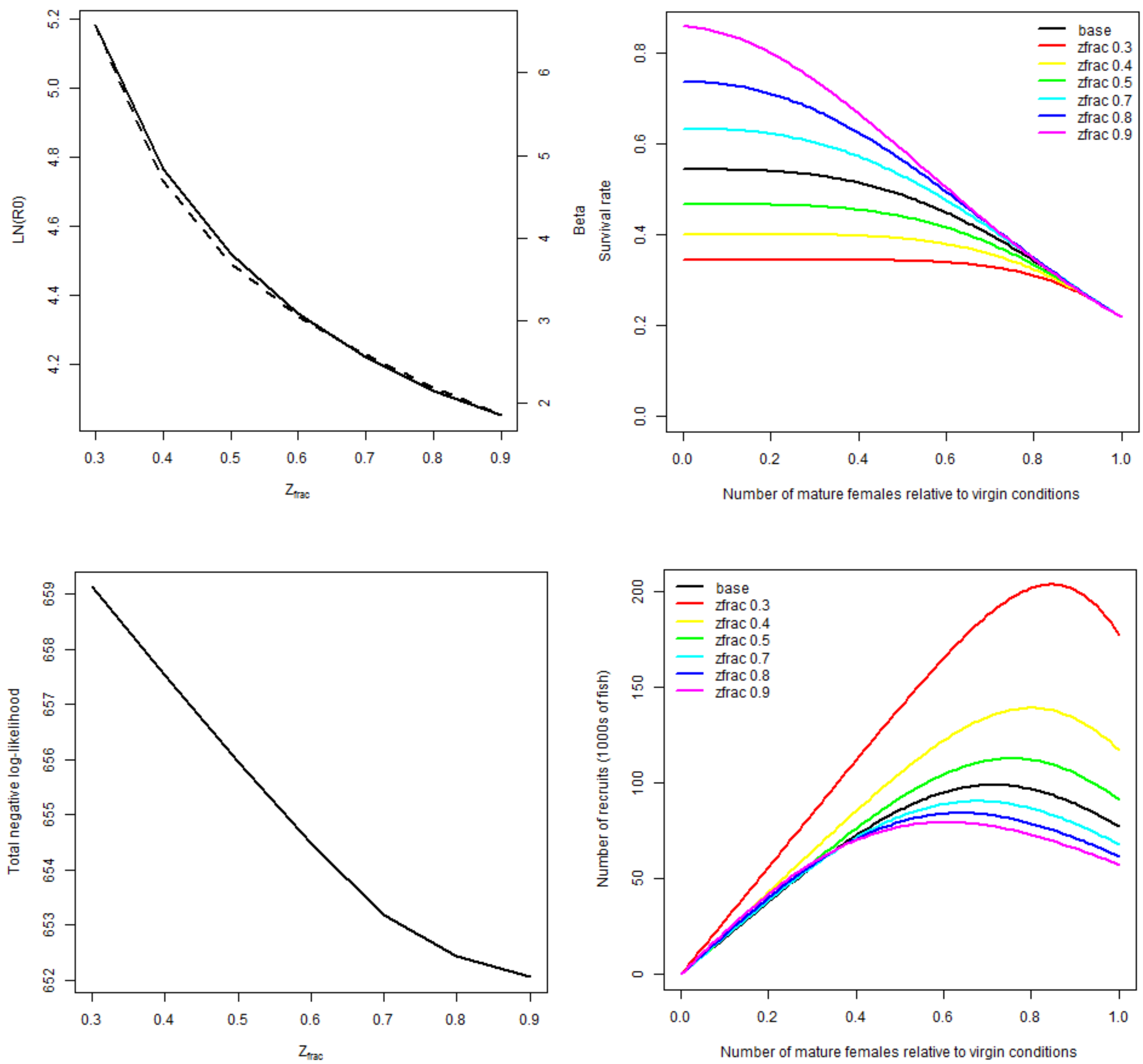


Figure 6.3. Estimated stock-recruitment relationship parameters of virgin recruitment (LN(*R0*): solid line) and shape parameter, (β: dashed line) (upper left), and total negative log-likelihood (lower left) under a range of fixed z_{frac} values. Expected pup survival (upper right) and recruitment (lower right) with respect to the number of mature females relative to virgin conditions, which is equivalent to spawning depletion, under a range of fixed z_{frac} values. The base case model has a fixed z_{frac} value of 0.6.

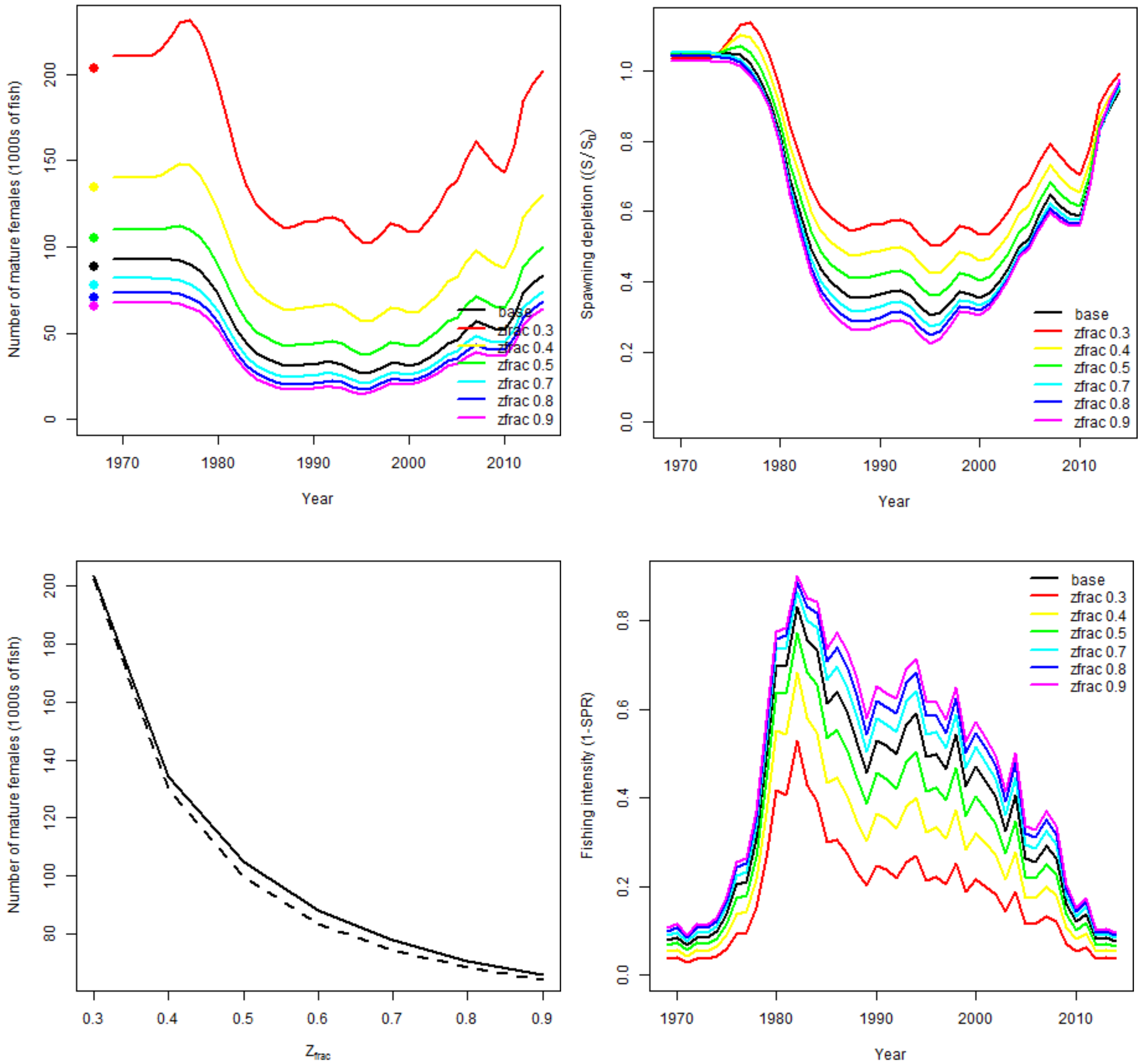


Figure 6.4. Estimated number of mature female sharks (upper left), number of mature female sharks under virgin conditions (lower left; solid line) and in the terminal year (2014) (lower left; dashed line), spawning depletion (upper right), and fishing intensity (1-SPR) (lower right) under a range of fixed z_{frac} values. The base case model had a fixed z_{frac} value of 0.6.

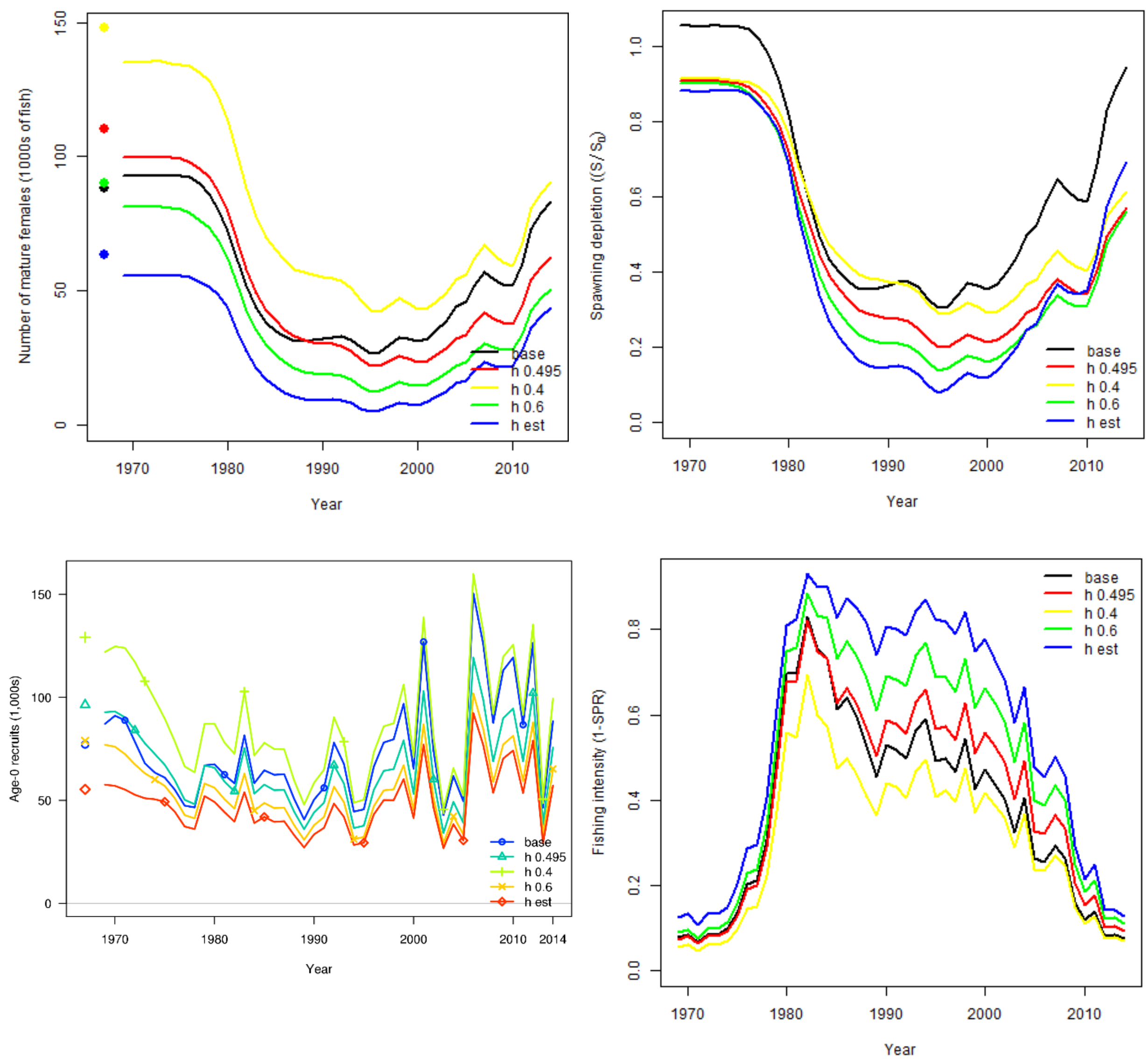
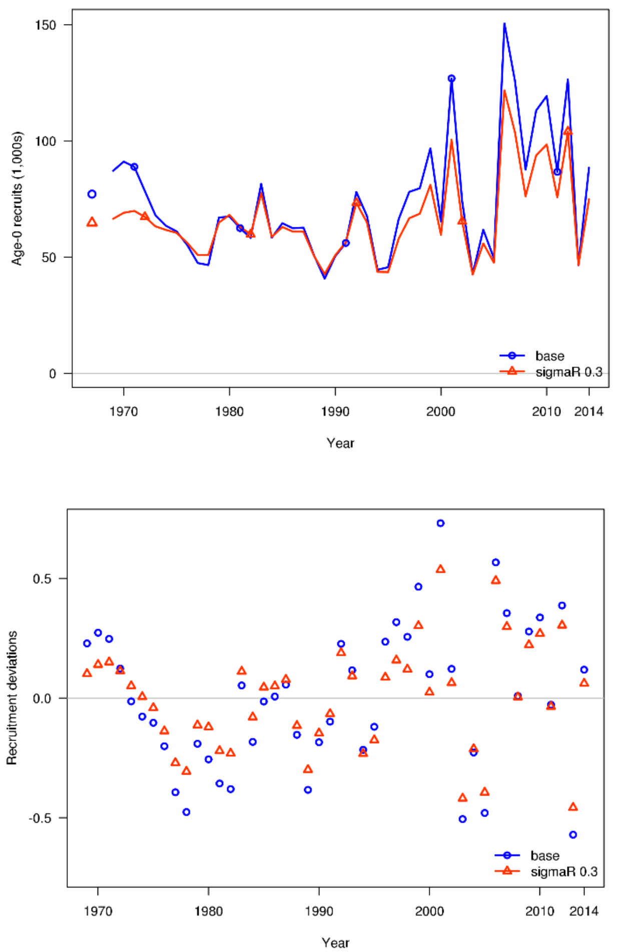


Figure 6.5. Estimated number of mature female sharks (upper left), recruitment (lower left), spawning depletion (upper right), and fishing intensity (1-SPR) (lower right) for the base case model (black) and several sensitivity runs assuming Beverton-Holt stock-recruitment relationships with steepness (h) equal to the base case model (h=0.495; red), slightly lower (h=0.4; yellow) and higher (h=0.6; green) than the base case model, and estimated steepness (h=0.89; blue).



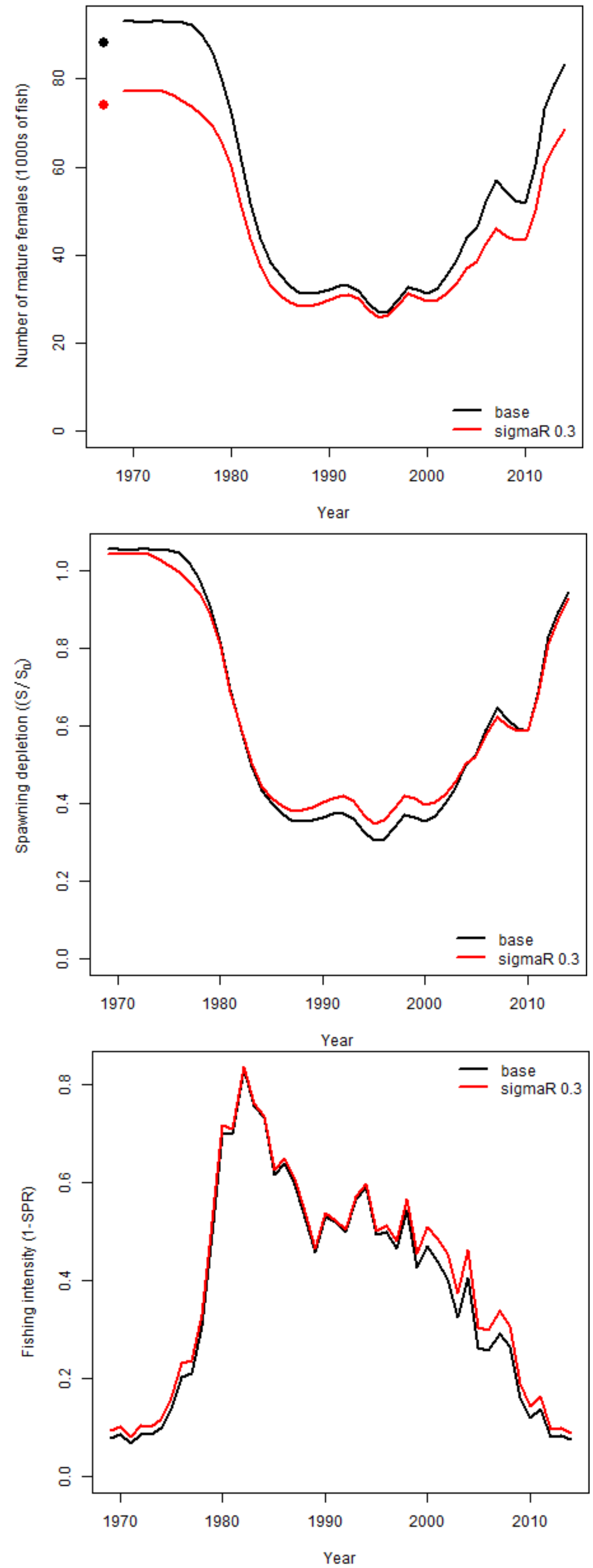


Figure 6.6. Estimated recruitment (upper left), recruitment deviates (lower left), number of mature female sharks (upper right), spawning depletion (middle right), and fishing intensity (1-SPR) (lower right) for the base case model (black) and a sensitivity run assuming a σ_R of 0.3 (red).

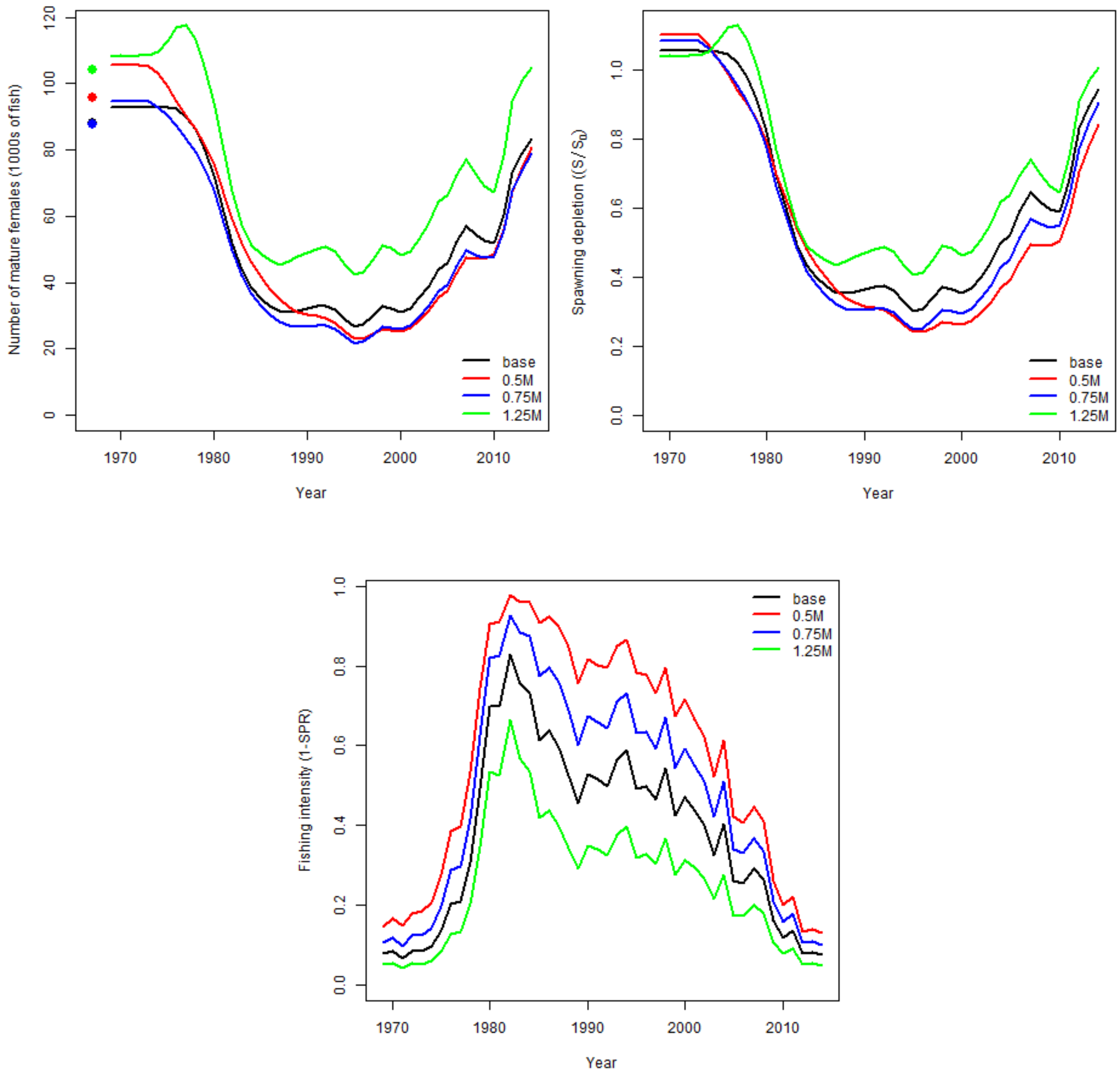
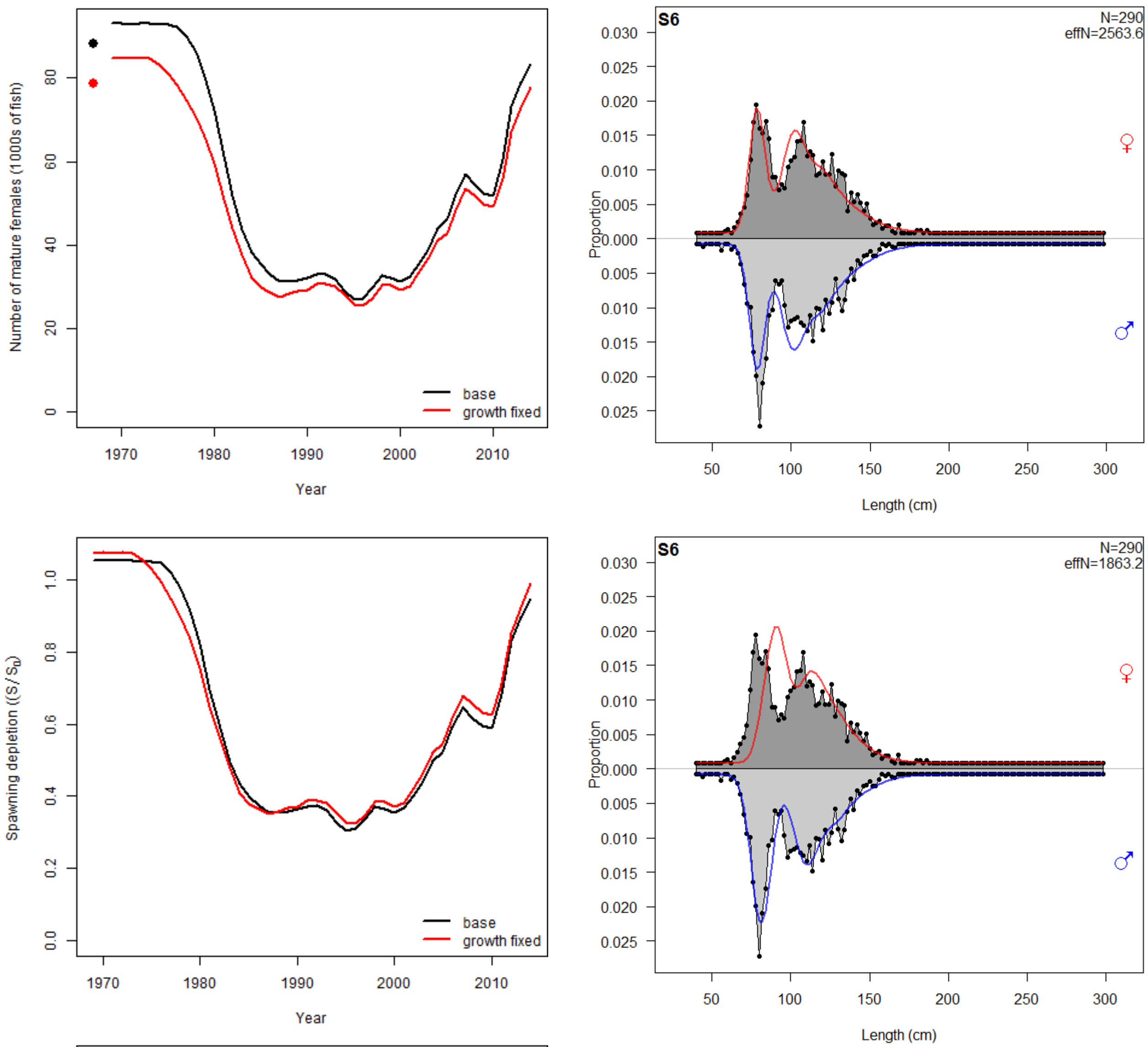


Figure 6.7. Estimated number of mature female sharks (upper left), spawning depletion (upper right), and fishing intensity (1-SPR) (lower) for the base case model (black) and sensitivity runs assuming various levels of natural mortality (50%, 75%, and 125% of the natural mortality used in the base case model). A sensitivity run was also performed at 1.5M but did not converge.



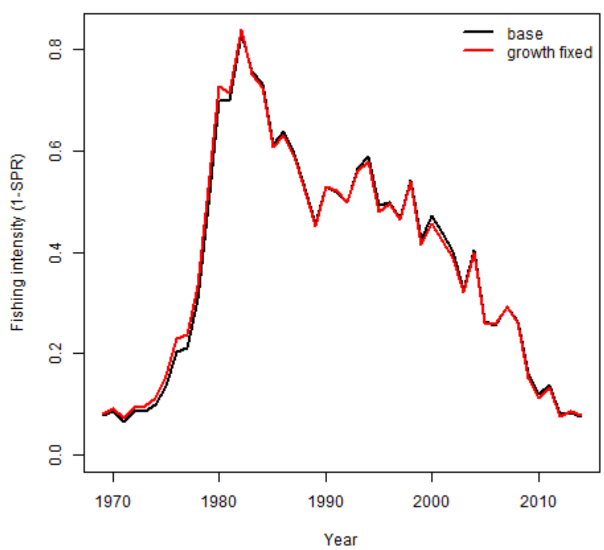


Figure 6.8. Estimated number of mature female sharks (upper left), spawning depletion (middle left), and fishing intensity (1-SPR) (lower left) for the base case model (black) and a sensitivity run assuming fixed sex-specific growth (Smith et al. 2008a). Overall model fits (red: female; blue: male) to the size compositions of the USJUV0614 (S6) survey (grey areas) are shown for the base case (upper right) and sensitivity run (lower right) models.

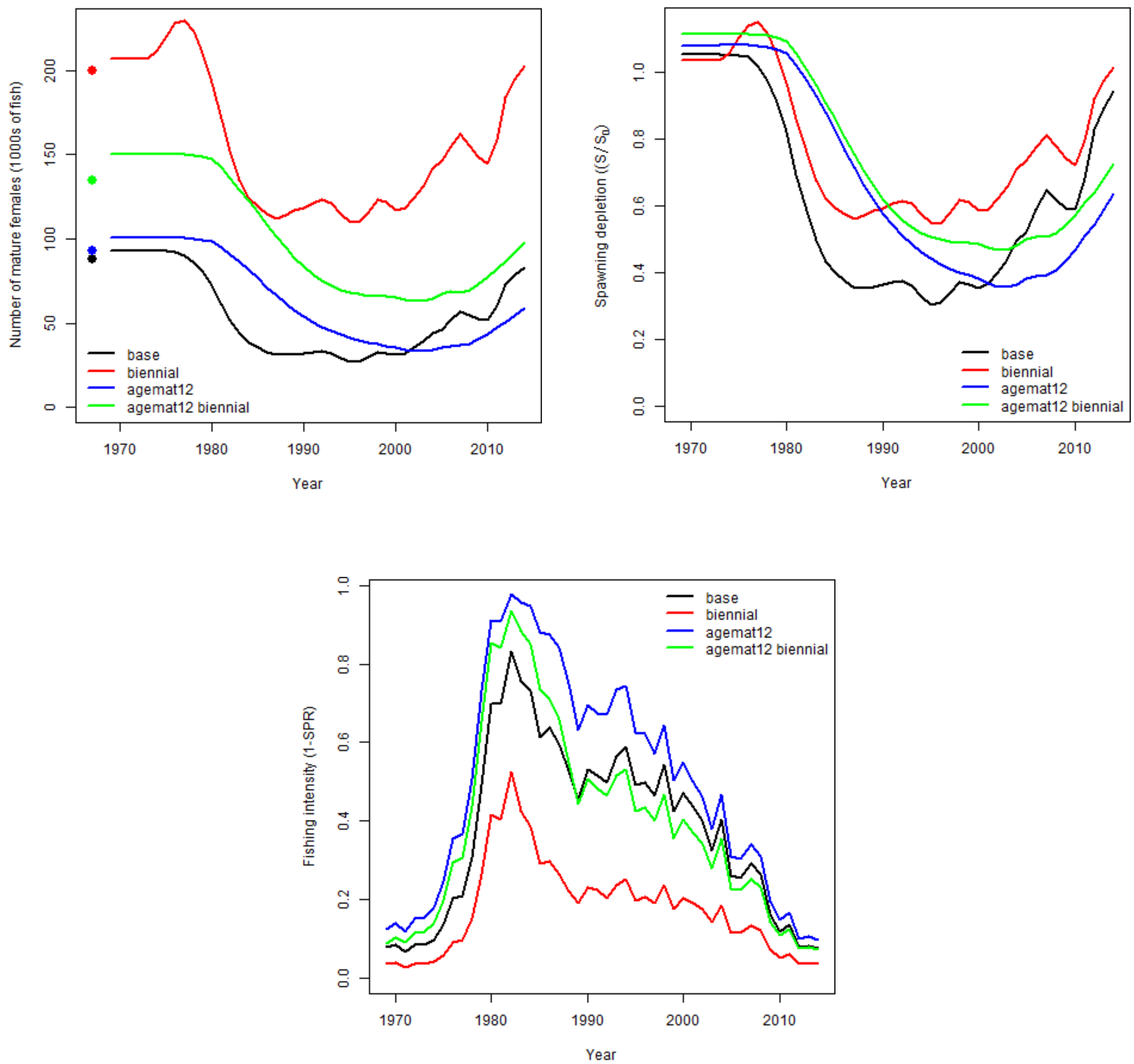


Figure 6.9. Estimated number of mature female sharks (upper left), spawning depletion (upper right), and fishing intensity (1-SPR) (lower) for the base case model (black) and sensitivity runs assuming a median age of maturity of 12 years, a biennial reproductive cycle, and a combination of both.

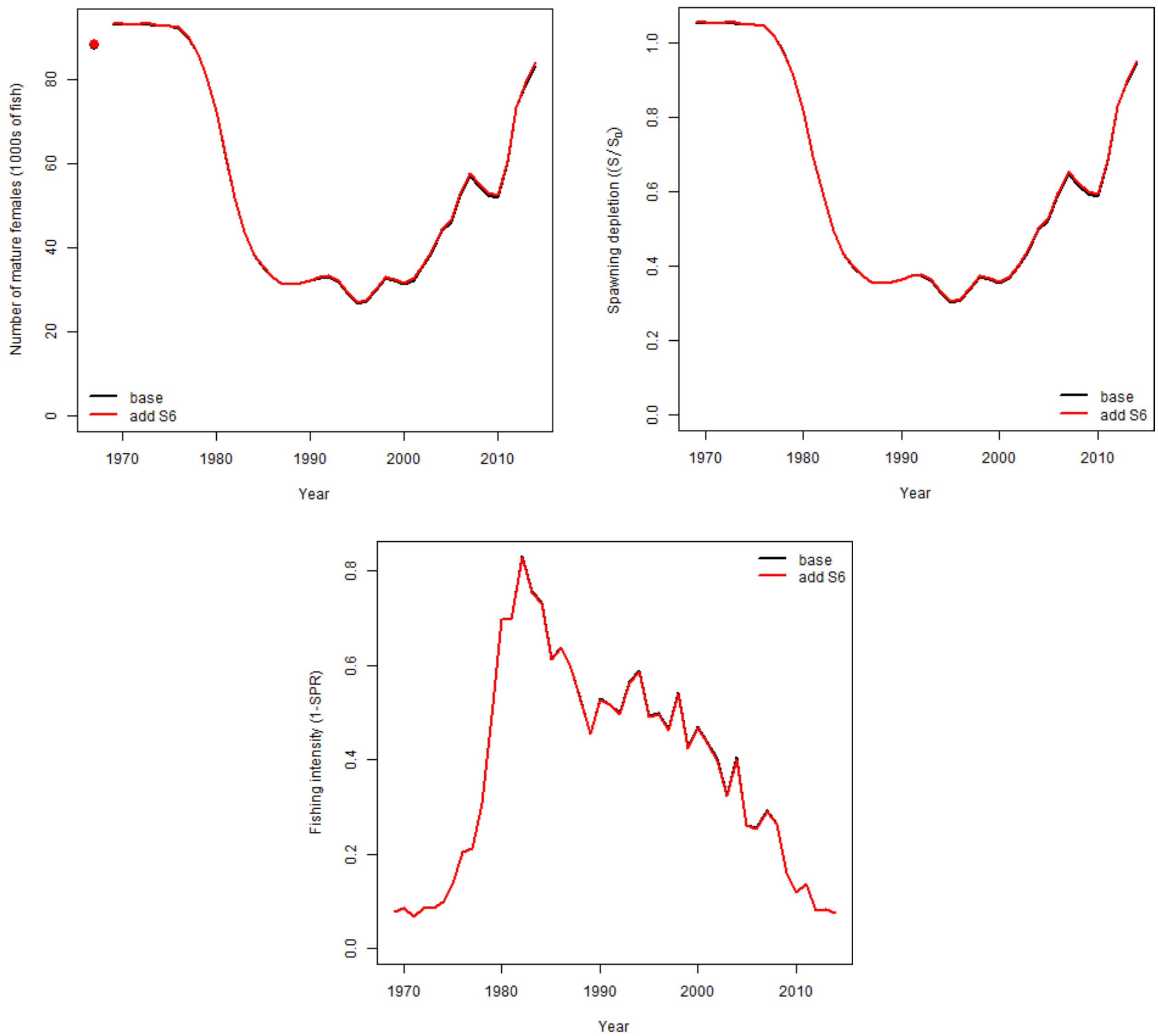


Figure 6.10. Estimated number of mature female sharks (upper left), spawning depletion (upper right), and fishing intensity (1-SPR) (lower) for the base case model (black) and a sensitivity run including the S6 index from the USA juvenile thresher survey.

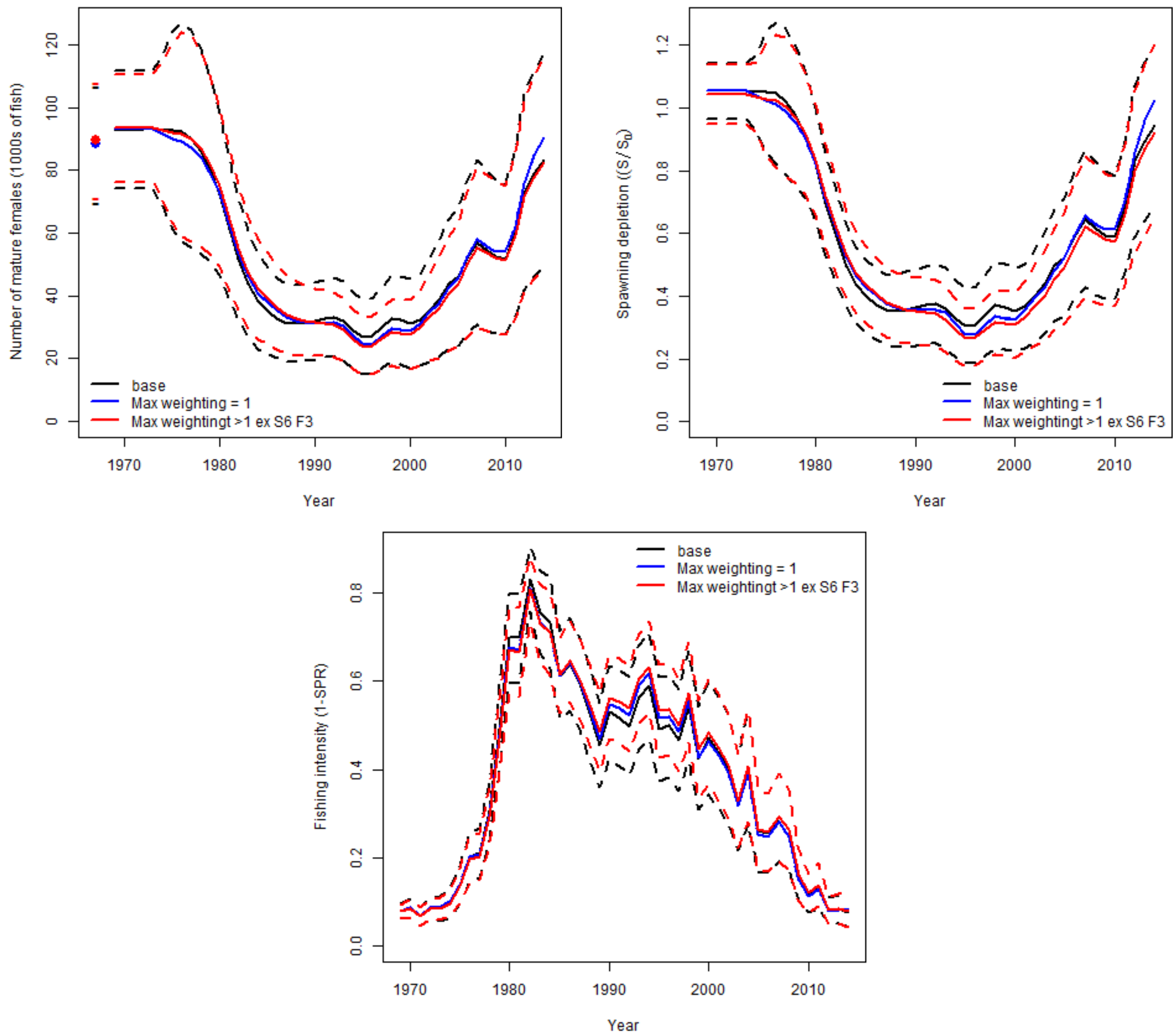


Figure 6.11. Estimated number of mature female sharks (upper left), spawning depletion (upper right), and fishing intensity (1-SPR) (lower) for the base case model (black) and sensitivity runs that allowed the weighting factors, calculated using the Francis (2011) method, for the size composition and conditional age-at-length data to be >1. Dashed lines indicate 95% confidence intervals. Confidence intervals could not be calculated when weighting factors for the USJUV0614 (S6) survey and the F3 fleet were >1 because of the non-positive definite Hessian matrix.

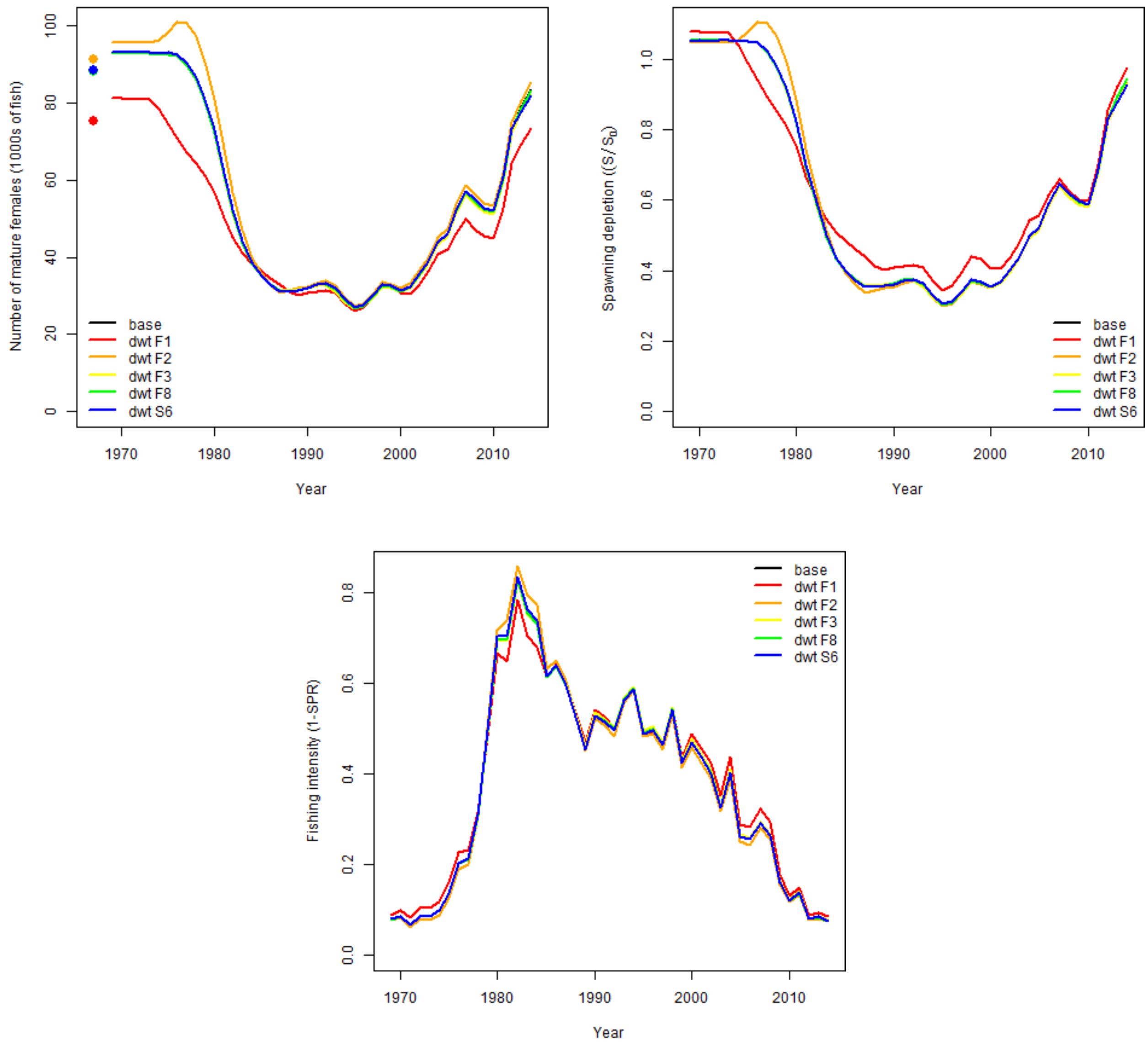


Figure 6.12. Estimated number of mature female sharks (upper left), spawning depletion (upper right), and fishing intensity (1-SPR) (lower) for the base case model (black) and sensitivity runs that down-weighted the size composition data from various fleets (F1, F2, F3, F8 and S6). Down-weighting the USSN (F3) fleet resulted in a non-positive definite Hessian matrix.

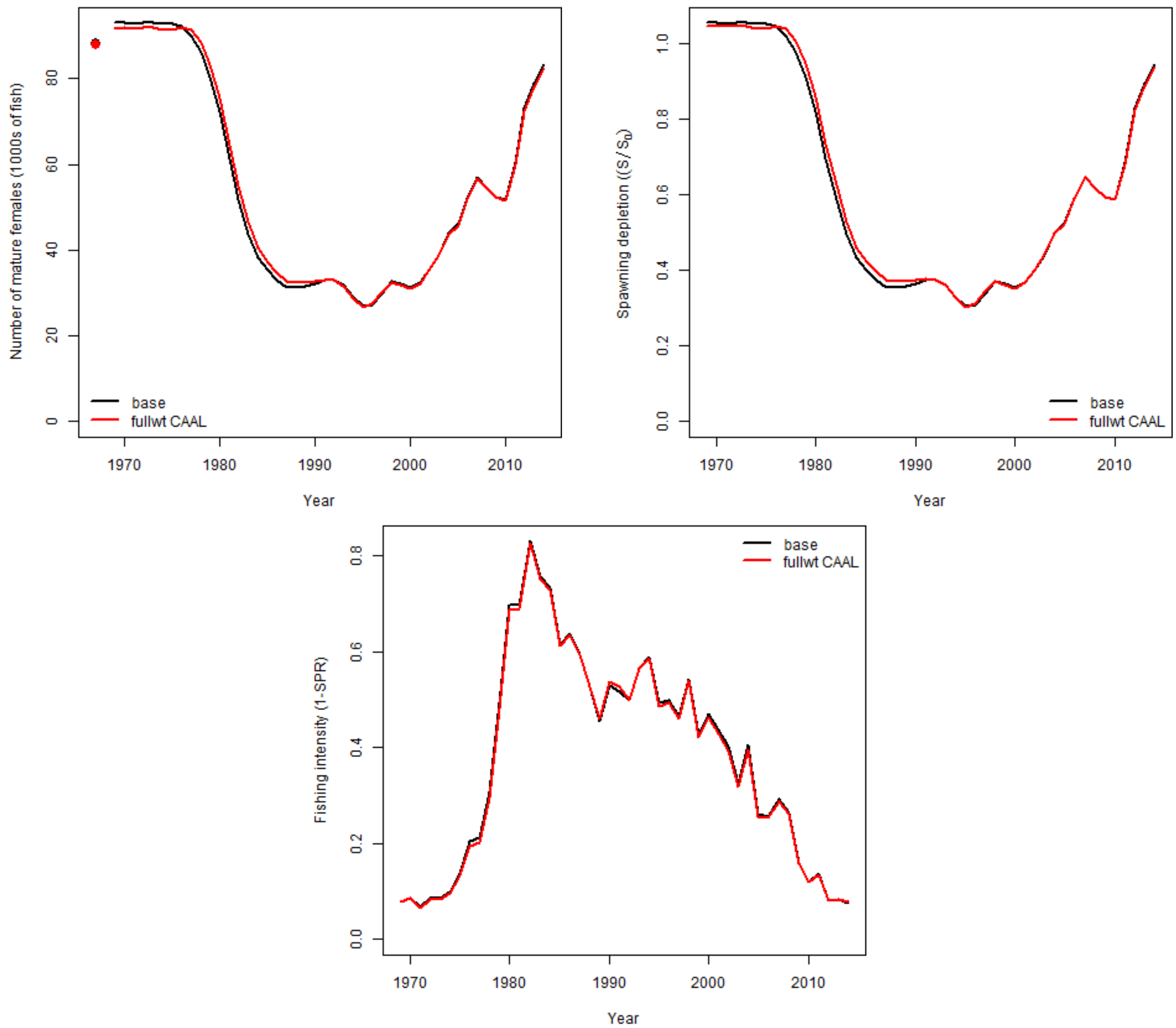


Figure 6.13. Estimated number of mature female sharks (upper left), spawning depletion (upper right), and fishing intensity (1-SPR) (lower) for the base case model (black) and a sensitivity run that up-weighted the conditional age-at-length data with weighting factors equal to 1.

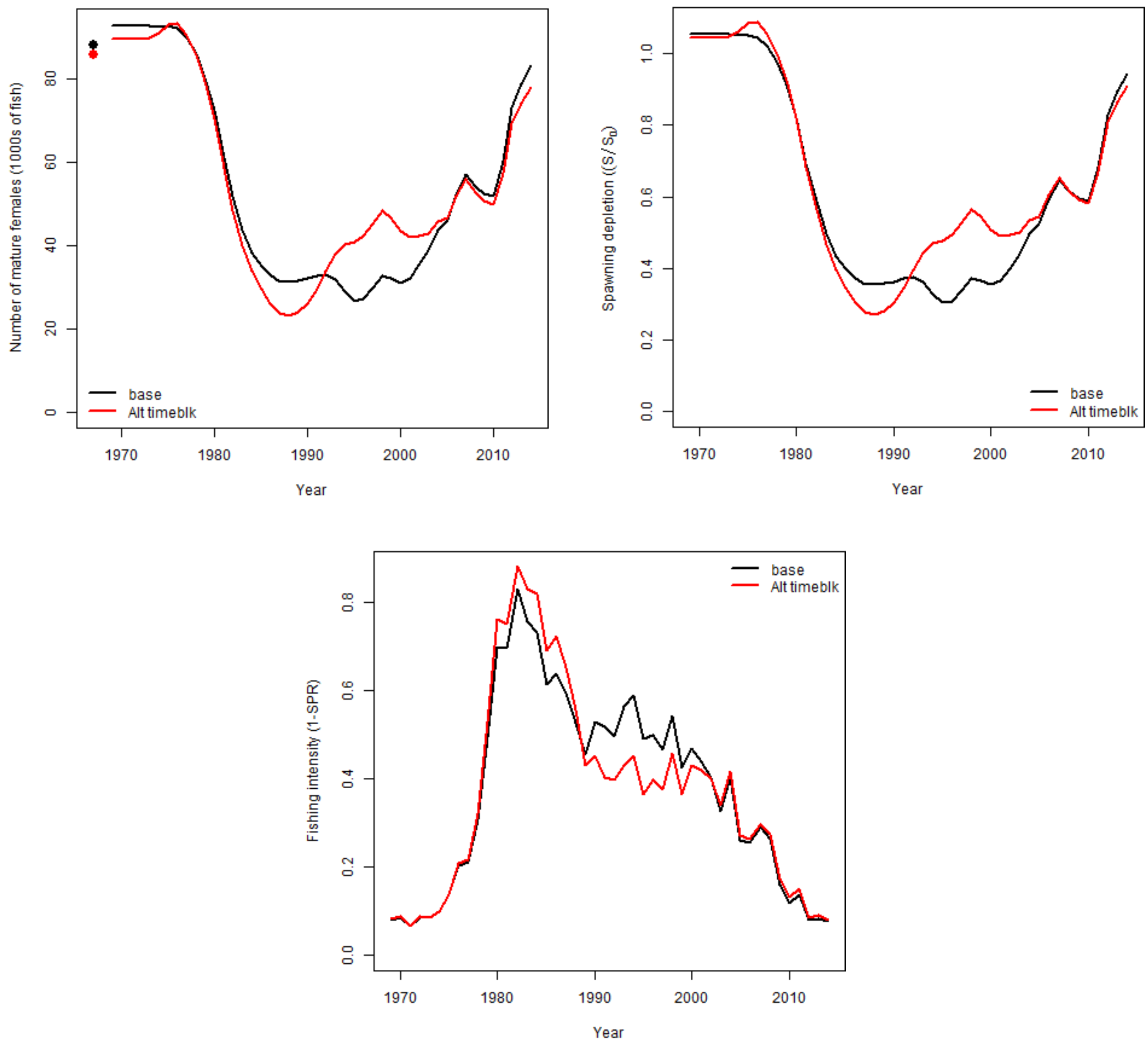


Figure 6.14. Estimated number of mature female sharks (upper left), spawning depletion (upper right), and fishing intensity (1-SPR) (lower) for the base case model (black) and a sensitivity run that used alternative selectivity time blocks (1985 – 2000 and 2001 – 2014).

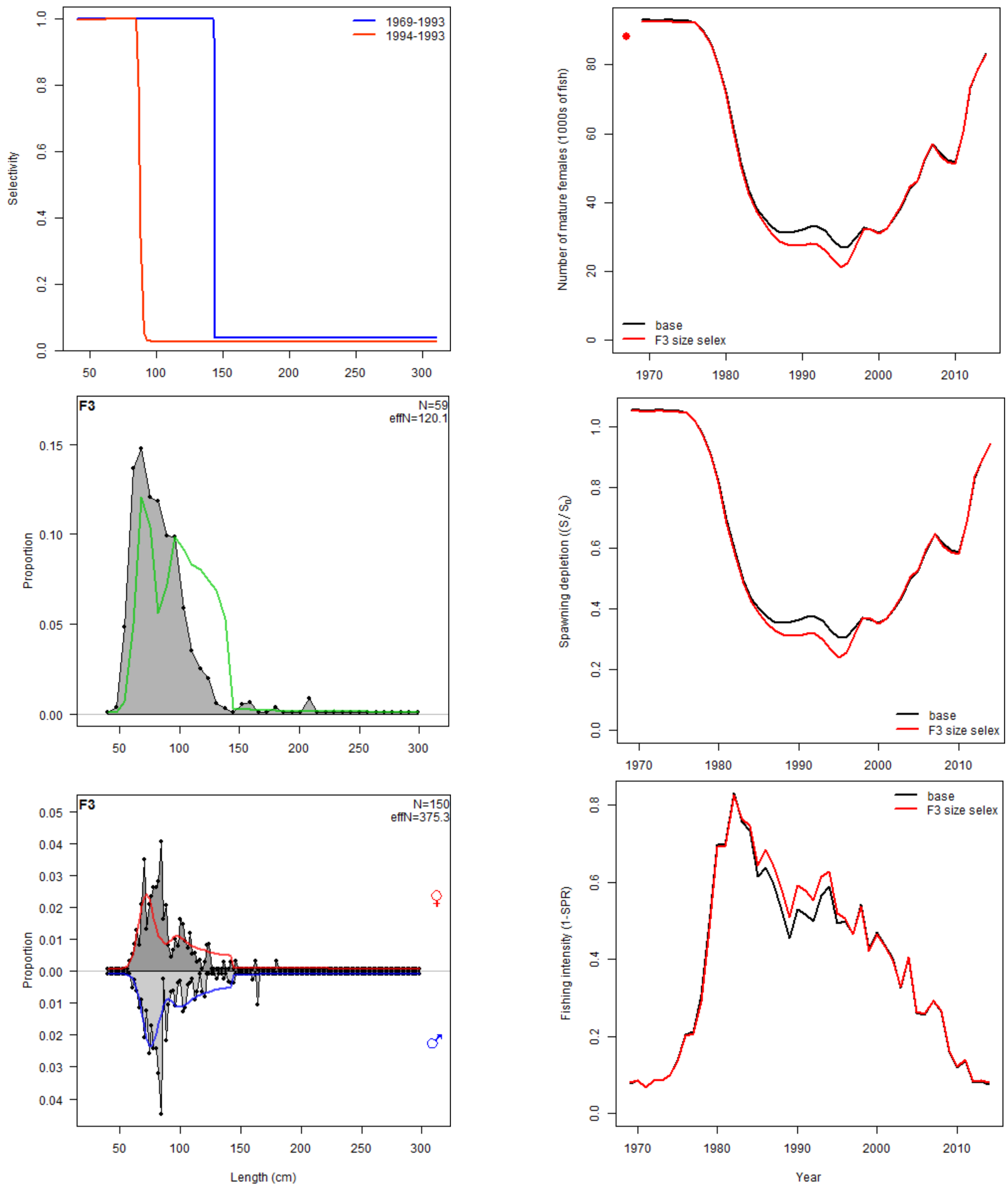
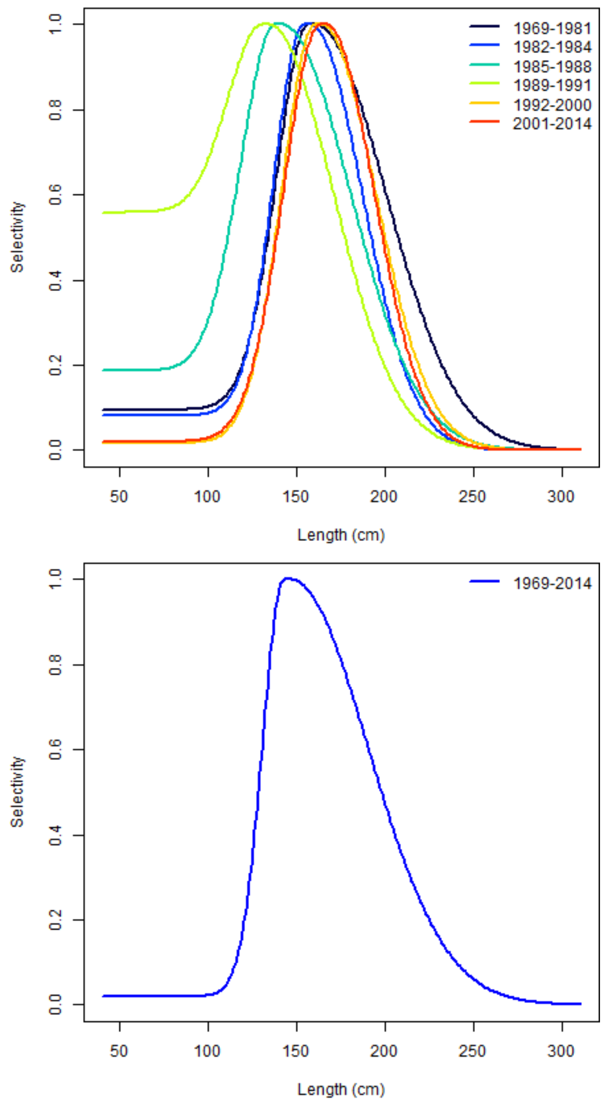


Figure 6.15. Estimated selectivity (upper left), and model fits to non-sex specific size composition (middle left) and size specific size composition (lower left) of the USSN (F3) fleet for a sensitivity run that used size selectivity for F3 instead of age selectivity. Estimated number of mature female sharks (upper right), spawning depletion (middle right), and fishing intensity (1-SPR) (lower right) for the base case model (black) and sensitivity run (red).



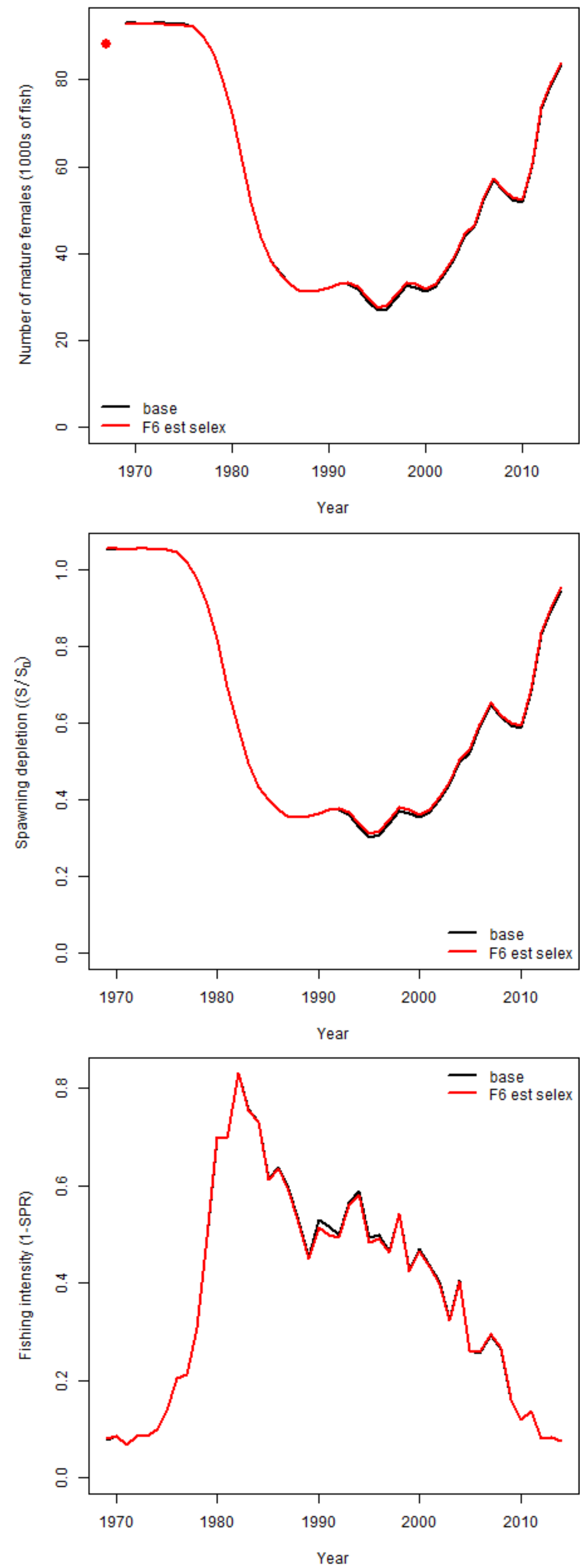


Figure 6.16. Selectivity of the MXDGNLL (F6) fleet for the base case model (upper left; assumed to be same as F1) and a sensitivity run that estimated the selectivity of F6 (lower left). Estimated number of mature females (upper right), spawning depletion (mid right), and fishing intensity (1-SPR) (lower right) for the base case model (black) and the sensitivity run.

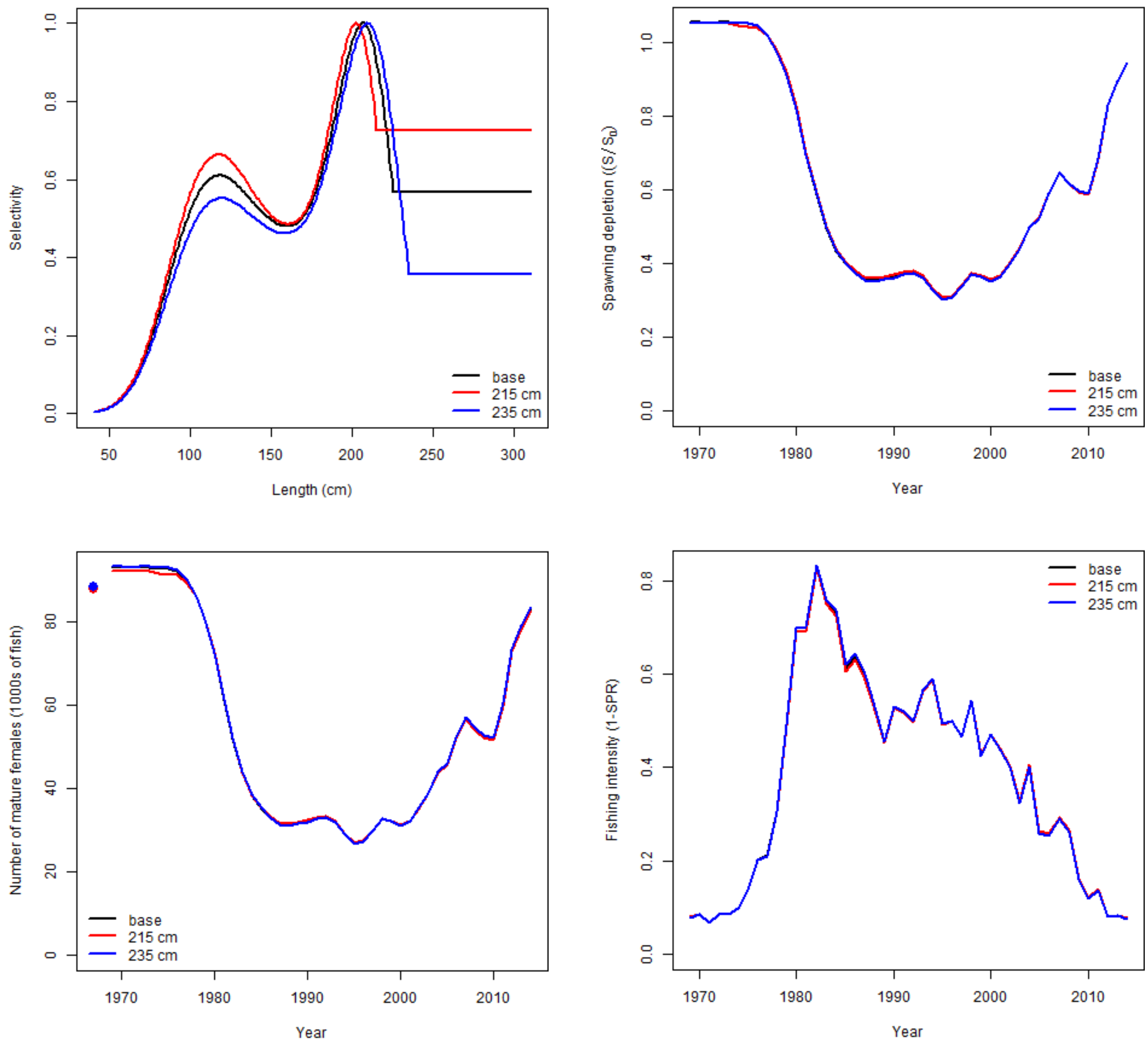


Figure 6.17. Estimated selectivity of the USDGNs2 (F2) fleet (1985 – 1988) for the base case model and two sensitivity runs with different positions on the last knot of the spline (upper left).. Estimated number of mature females (upper right), spawning depletion (mid right), and fishing intensity (1-SPR) (lower right) for the base case model (black) and sensitivity runs.

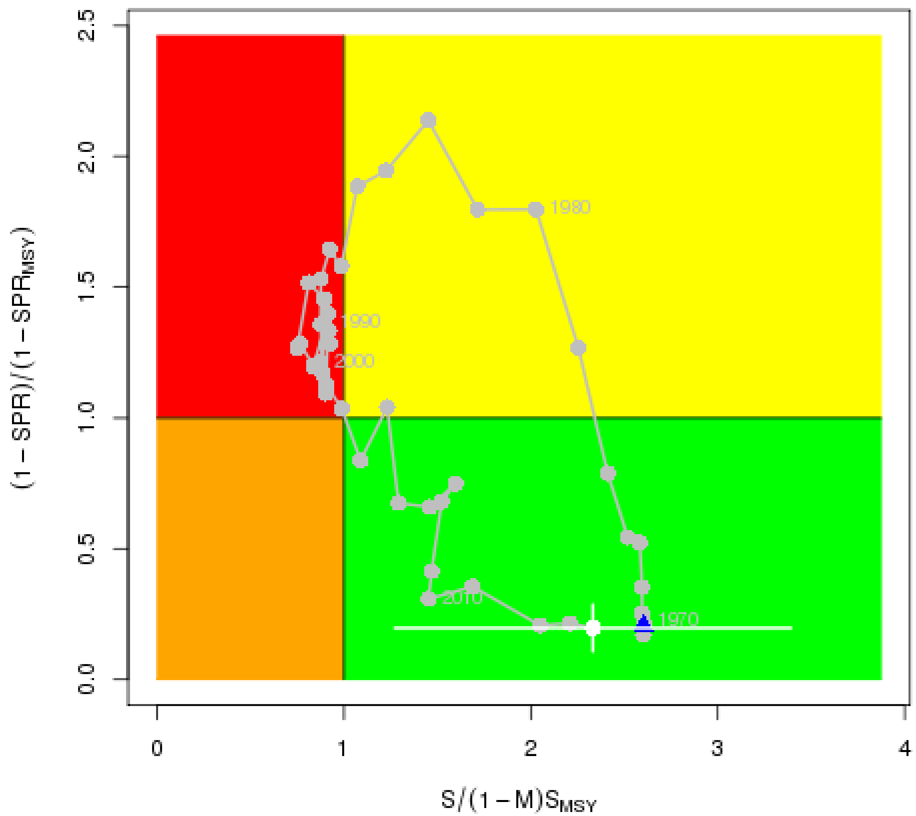


Figure 8.1. Kobe time series plot of the ratio of spawning abundance (S; number of mature female sharks) relative to the minimum stock size threshold reference point (MSST; (1-M)*S_{MSY}) and ratio of the fishing intensity (1-SPR) relative to the maximum fishing mortality threshold (MFMT; 1-SPR_{MSY}) for the base case model. Values for the start (1969) and end (2014) years are indicated by blue triangle and white circle, respectively. White lines indicate the 95% confidence intervals. Grey numbers indicate selected years.

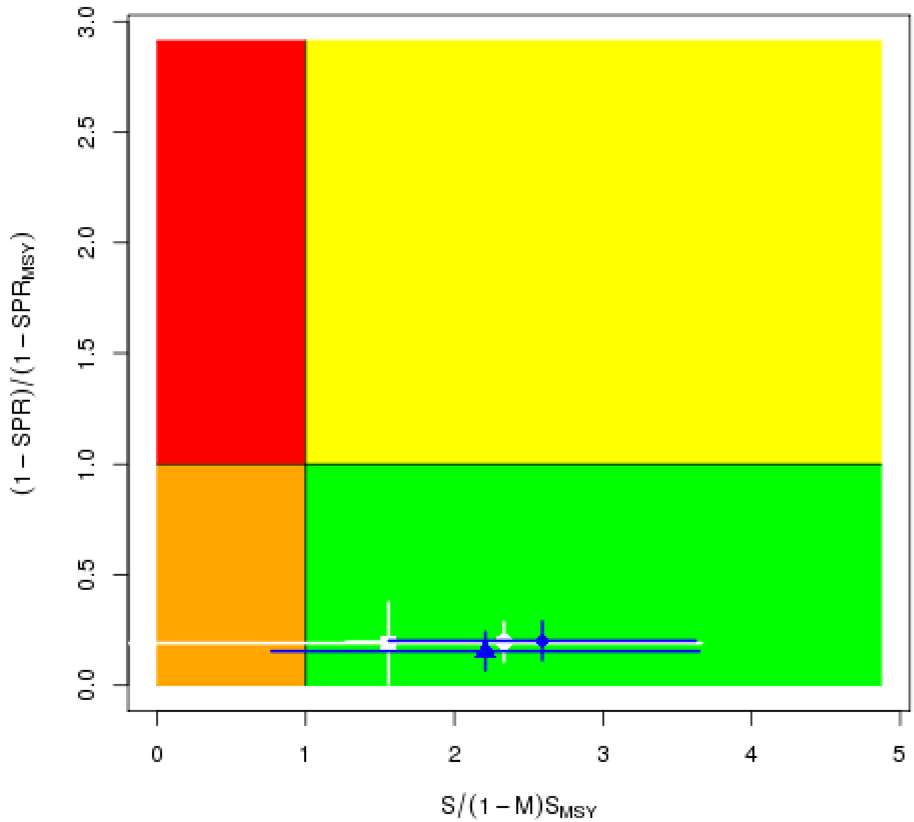


Figure 8.2. Kobe plot of the ratio of spawning abundance (S; number of mature female sharks) relative to the minimum stock size threshold reference point (MSST; (1-M)*S_{MSY}) and ratio of the fishing intensity (1-SPR) relative to the maximum fishing mortality threshold (MFMT; 1-SPR_{MSY}) for the end year (2014) of the base case model (white circle) and three alternative states of nature: 1) alternative reproductive biology with a biennial reproductive cycle, 12 years median age-at-maturity, and natural mortality of 0.0757 (white square); 2) alternative stock-recruitment with z_{frac} of 0.4 (blue triangle); and 3) alternative stock-recruitment with z_{frac} of 0.8 (blue diamond). White and blue lines indicate the respective 95% confidence intervals.

APPENDIX A: Abundance indices for the USA swordfish/shark gillnet fishery

INTRODUCTION

The most important commercial fishery for common thresher sharks is the USA swordfish/shark drift gillnet (USDGN) fishery, which began in 1977-78 (Hanan et al. 1993). The USDGN fishery began with about 15 vessels in Southern California but the number of vessels grew rapidly (Hanan et al. 1993). Although the initial primary targets were common thresher and shortfin mako sharks, fishermen soon discovered that they could efficiently catch swordfish with the same gear, and switched to primarily targeting swordfish because of substantially higher ex-vessel prices (Hanan et al. 1993). Since those early days, the primary target of the USDGN fishery has been swordfish, with common thresher and shortfin mako sharks being secondary targets.

Fishing operations of the USDGN fishery have been heavily regulated to reduce adverse interactions with other fisheries, fishing mortality of common thresher sharks, and incidental bycatch of marine mammals and sea turtles (Hanan et al. 1993; PFMC 2003). Details of current and historical regulations have been documented by Hanan et al. (1993), PFMC (2003), and PFMC (2015) (Table 1.1 in the main document). There appeared to be three major periods for the USDGN fishery with respect to fishery operations and regulations: 1) 1977 – 1991; 2) 1992 – 2000; and 3) 2001 – 2014. The first period (1977-1991) encompassed the initial expansion of the fishery and the switch from primarily targeting pelagic sharks to swordfish. There were also early attempts at regulating the USDGN fishery, which resulted in frequent changes in regulations that included gear restrictions, swordfish catch, swordfish to shark catch ratios, seasonal closures, and time-area closures. In particular, time-area closures in California were enacted or modified in 1982, 1985, and 1989, which likely affected the CPUE of sharks for the USDGN fishery (Urbisci et al. in review). Washington and Oregon also started and closed their drift gillnet fisheries in 1983 and 1989 respectively. The time-area closures for the USDGN fishery was relatively stable during the second period (1992 – 2000), after the closure period for California was changed to May 1 through August 14 in 1992. The second period was a period of decline in the USDGN fishery, with the number of vessels landing fish declining from 119 in 1992 to 72 in 2000 (PFMC 2015). This decline continued in the third period (2001 – 2014), which was marked by the enactment of a large time-area closure in 2001 to protect leatherback turtles. The number of vessels in the USDGN fishery landing fish declined from 61 in 2001 to 18 in 2014 (PFMC 2015).

Three indices representing different regulatory and operational periods were developed for the USDGN fishery: Index 1: 1982 – 1984; Index 2: 1992 – 2000; and Index 3: 2001 – 2013. Changes in the regulations and fishery operations of this fishery have likely affected the catchability of this fishery (Urbisci et al. in review). The most important regulatory changes occurred in 1982, 1985, 1989, 1992, and 2001, when time-area closures were implemented or changed. For this assessment, we did not attempt to account for the effect of these time-area closures in our GLMs. Instead, we developed shorter time series within the periods when regulatory changes were likely less important. Logbook data for 2014 was also not available by the time that development of abundance indices was completed. An abundance index was not developed for the 1985 – 1991 period because of changing regulations and fishery operations. In addition, preliminary examination of the logbook data indicated that the CPUE of the fishery rapidly increased and decreased several fold during this period, which indicated that changing regulations and fishing operations likely resulted in the exploitation of some local areas of high thresher abundance.

Regulatory changes have affected the start of the fishing season over the years. Therefore, only data from seasons 3 and 4 (i.e., Aug – Oct and Nov – Jan) were used for the abundance indices because fishing consistently occurred during those seasons. Three bimonthly periods within the six month period were used as factors in the GLMs to account for changes in thresher CPUE due to time of year.

The annual decile rank of swordfish catch of a given drift gillnet set was included in the GLMs to account for shifts in the targeting by the fishery from pelagic sharks to swordfish. In the initial development of the fishery, the primary target of the fishery changed from pelagic sharks to swordfish because of higher market prices. However, the targeting switch was constrained by regulations restricting the total amount of monthly swordfish landings and requirements to land equal amounts of shark. Even after regulations restricting swordfish catch were removed, USDGN vessels likely switched between swordfish and pelagic sharks depending on availability and market prices. The annual decile rank of swordfish catch was determined by ranking the swordfish catch from all sets within a given year, and then splitting the ranks into deciles (e.g., 0-10%, 10-20%).

MATERIALS AND METHODS

Data

The abundance indices were developed from set-by-set logbook data submitted by skippers of vessels in the USDGN fishery after a mandatory logbook program was established in 1980, with the initial data collected in the 1981 – 1982 fishing season (Hanan et al. 1993). Data collected by the logbooks include catch (numbers of fish) by species, date, mesh size, net length, hours soaked, set number, and geographical position. Geographical positions were entered as CDFG block numbers (predominantly 10 min by 10 min squares), which were subsequently converted to latitudes and longitudes based on the center of the blocks. Coverage rate of the logbooks (proportion of landed weight reported in the logbooks) was estimated by Hanan et al. (1993) to be poor in the 1981 – 1982 fishing season (1% for thresher sharks) but was very good for all subsequent years, exceeding 100% coverage for most years. The catch and effort in the logbook data therefore appeared to be representative of the fishery, except for the 1981 – 1982 season.

Preliminary examination of the data indicated that two stages of filtering were required before the data could be used for developing abundance indices. The number of sets in the data after each filtering stage is summarized in Table A.1 and the spatial distribution of the sets and catch can be seen in Fig. A.1. The two filtering stages were:

1. Identifying swordfish/shark (large-mesh) drift gill net sets

The original data set included data from small-mesh drift gillnet and set net fisheries targeting coastal and demersal fish species but did not specifically identify sets from the swordfish/shark fishery using large-mesh drift gillnets. The logbook data were therefore filtered to select for data where gear type was identified as "drift gillnet", and target species identified as swordfish and/or shark, and mesh size was ≥14 inches or unspecified.

2. Identifying abnormal fishing operations

The majority of fishing operations for the USDGN fishery used nets about 1,000 fathoms long and had soak times within 24 hours. However, abnormal fishing operations could result from nets being left in the water, and experimental trips using shorter nets and/or soak times. Sets with abnormal fishing operations or misreported information were identified and removed in the second filtering stage because it was considered inappropriate to use data from these abnormal fishing operations. Abnormal sets were identified based on fishery knowledge. As a result, sets that recorded missing or abnormal soak times (<3 or >17 hours), net lengths (<250 or >2000 m), mesh size (<14 or >23 inches), locations (latitude: <32 or >45°N; distance from shore: >200 km), and depth (>6201 m). In addition, only data from August through January were used for the abundance indices in order to maintain consistency with the fleet definitions used in the assessment model.

The logbook data were divided into strata based on available factors. Season was categorized as three bimonthly periods ([Aug, Sep], [Oct, Nov], [Dec, Jan]). Five areas were defined based on the latitude ([32, 34), [34, 36), [36, 38), [38, 40), and ≥40°N). Other factors included water depth (11 levels: [0, 250), [250, 500), [500, 750), [750, 1000), [1000, 1250), [1250, 1500), [1500, 1750), [1750, 2000), [2000, 3000), [3000, 4000), and ≥4000 m), distance from shore (7 levels: [0, 25), [25, 50), [50, 75), [75, 100), [100, 125), [125, 150), and ≥150 km), mesh size (3 levels: unknown, [14, 19), and ≥19 inches), and percentile rank of swordfish catch (swfrank) (10 levels: [0, 10), [10, 20), [20, 30), [30, 40), [40, 50), [50, 60), [60, 70), [70, 80), [80, 90), [90, 100]%).

Models

Delta-lognormal models (Lo et al. 1992) were used to standardize the catch per unit effort (CPUE) to obtain the abundance indices used in the stock assessment because the data set contained a large proportion of sets with zero thresher catch (Fig. A.2). Catch was defined as the sum of all kept and discarded common thresher sharks in a single set, and effort was defined as the product of the length of the net (km) and soak time (hours). Delta-lognormal models assumes that the proportion of sets with positive catch have a binomial error structure and is modeled by a GLM with a logit link function, and the catch rate of sets with positive catch has a lognormal error distribution and is modeled by a lognormal GLM. The standardized index is the product of the back-transformed marginal year effects (Searle 1980) of these two components, with a correction for the bias in the lognormal back transformation. Estimates of variance were obtained by jackknifing the data set, using a modified version of delta_glm_1-7-2 function (E. J. Dick, pers. comm.) in R (function was modified to allow for different explanatory factors for the binomial and lognormal functions).

A forward-backward stepwise model selection process, with AIC as the selection criteria, was used to determine the set of factors that explained the catch of common thresher sharks in the logbook data. The binomial and lognormal models for each time period were selected independently.

RESULTS AND DISCUSSION

Based on the stepwise model selection process, the final delta-lognormal models for each time period were:

<u>1982 – 1984</u>
Binom: logit(π) ~ year + lat + season + distance + swfrank + depth + offset[log(eff)] + ε
Lognormal: log(catch) ~ year + lat + season + distance + swfrank + depth + offset[log(eff)] + ε

<u>1992 – 2000</u>
Binom: logit(π) ~ year + lat + season + distance + swfrank + depth + mesh + offset[log(eff)] + ε
Lognormal: log(catch) ~ year + lat + distance + swfrank + depth + mesh + offset[log(eff)] + ε

<u>2001 – 2013</u>
Binom: logit(π) ~ year + lat + season + distance + swfrank + depth + mesh + offset[log(eff)] + ε
Lognormal: log(catch) ~ year + lat + season + distance + swfrank + depth + mesh + offset[log(eff)] + ε

where π was the probability of a set having positive common thresher shark catch, and the random error structures of the binomial and lognormal models were assumed to be Binom(n, π) and N(0, σ) respectively. Deviance tables for the three time periods are found in Table A.2. No first-order interactions were included in the final model selection process because abundance indices with or without first-order interactions were highly similar.

Model diagnostics indicated adequate performance of the lognormal and binomial models for all three abundance indices (Fig. A.3 – A.8). For all three time periods, the lognormal residuals were slightly skewed because the lognormal models had problems fitting sets with small numbers of fish. However, the mean predicted values of both the lognormal and binomial component models were highly representative of the observed values after aggregation into spatial and temporal bins.

In the first time period (1982 – 1984), the standardization resulted in an abundance index that was more consistently and more steeply declining than the nominal CPUE (Fig. A.9). The standardized abundance index for the second time period (1992 – 2000) indicated that the common thresher shark population was increasing rapidly during this period but there were moderate amounts of variability in the estimates (Fig. A.10). The lognormal model reduced the variability apparent in the CPUE of positive sets but the variability in the binomial component was not visibly reduced. The third period (2001 – 2013) was marked by high interannual variability in the relative abundance estimates and there were no obvious trends during this period (Fig. A.11). The jackknife procedure resulted in coefficients of variation (CVs) that were relatively high, especially for 1982 – 1984 (Table A.3 and Fig. A.12).

Appendix Table A.1. Amount of data (number of sets) in the logbook data set before and after two stages of filtering for the swordfish/shark drift gillnet fishery.

Period	**Number of sets prior to filtering**	**Number of sets after stage 1 filtering**	**Number of sets after stage 2 filtering**
1982 – 1984	83116	31173	21950
1992 – 2000	79428	28245	25305
2001 – 2013	47844	11511	9699

Appendix Table A.2. Deviance analysis of explanatory variables in delta-lognormal models for common thresher shark catch rates of USA swordfish/shark drift gillnet fishery for three time periods: 1) 1982 – 1984; 2) 1992 – 2000; and 3) 2001 – 2013.

1982 - 1984

Model factors	Df	Deviance	Residual Df	Residual Deviance	Pr(>Chi)
Binomial: AIC = 21735					
Null			21949	23219	
Year	2	38.18	21947	23180	5.13E-09
Latitude	4	735.70	21943	22445	<2.2E-16
Season	2	184.29	21941	22260	<2.2E-16
Distance from shore	6	374.49	21935	21886	<2.2E-16
Decile rank of swordfish catch	8	99.22	21927	21787	<2.2E-16
Depth	10	118.16	21917	21669	<2.2E-16
Lognormal: AIC = 11416					
Null			4628	4555.1	
Year	2	37.71	4626	4517.4	1.1E-12
Latitude	3	848.51	4623	3668.9	<2.2E-16
Season	2	67.36	4621	3601.6	<2.2E-16
Distance from shore	6	232.39	4615	3369.2	<2.2E-16
Decile rank of swordfish catch	8	123.23	4607	3245.9	<2.2E-16
Depth	10	98.80	4597	3147.2	<2.2E-16

Appendix Table A.2. Continued.

1992 – 2000

Model factors	Df	Deviance	Residual Df	Residual Deviance	Pr(>Chi)
Binomial: AIC = 18802					
Null			25304	21690	
Year	8	660.11	25296	21030	<2.2E-16
Latitude	4	230.86	25292	20799	<2.2E-16
Season	2	129.00	25290	20670	<2.2E-16
Distance from shore	6	1075.00	25284	19595	<2.2E-16
Decile rank of swordfish catch	8	508.04	25276	19087	<2.2E-16
Depth	10	358.66	25266	18728	<2.2E-16
Mesh	2	8.47	25264	18720	0.0145
Lognormal: AIC = 10043					
Null			3704	4767.4	8.0E-09
Year	8	46.75	3696	4720.7	<2.2E-16
Latitude	4	752.55	3692	3968.1	<2.2E-16
Distance from shore	6	400.48	3686	3567.7	<2.2E-16
Decile rank of swordfish catch	8	264.60	3678	3303.1	<2.2E-16
Depth	10	105.79	3668	3197.3	<2.2E-16
Mesh	2	4.33	3666	3192.9	0.0837

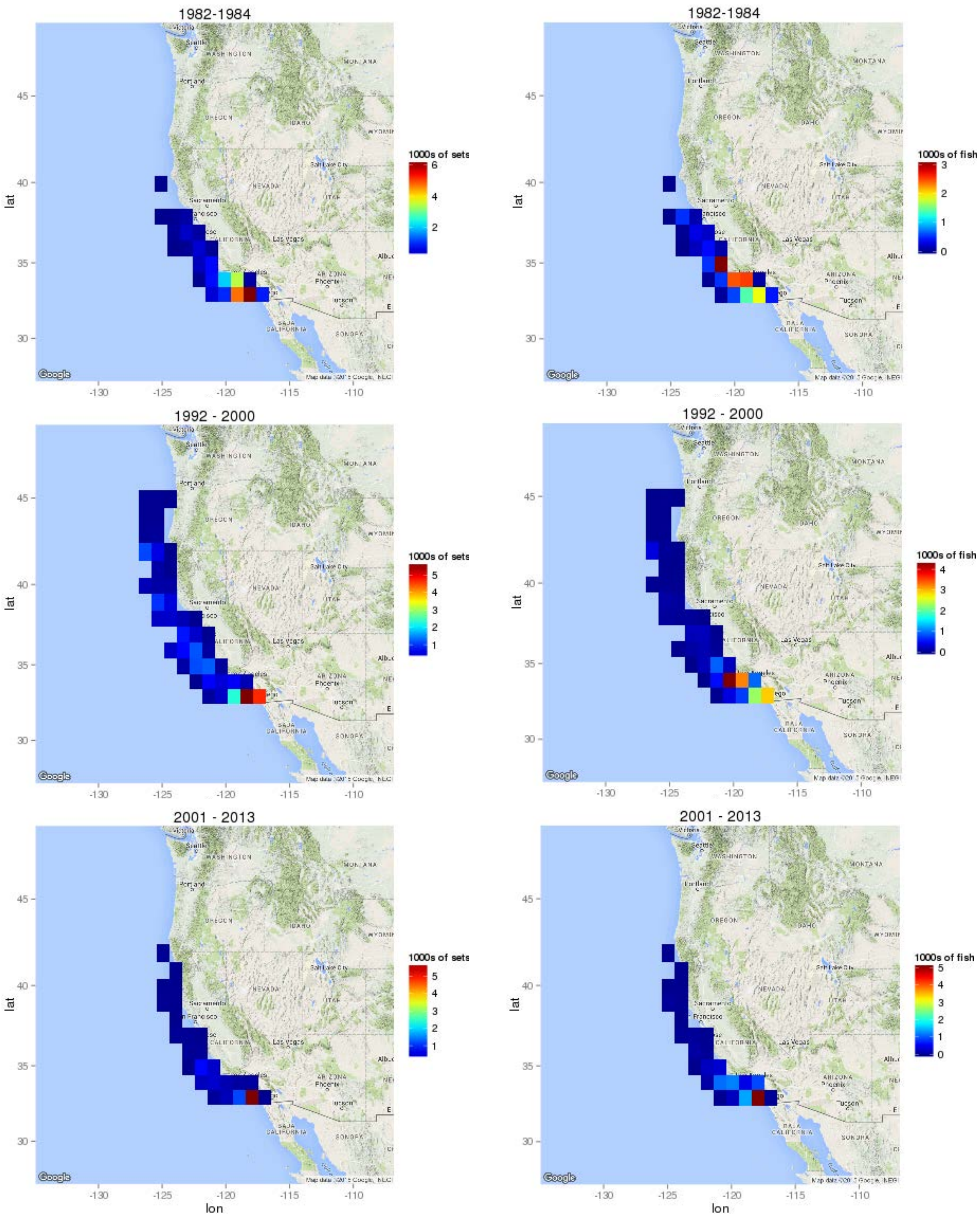
Appendix Table A.2. Continued.

2001 – 2013

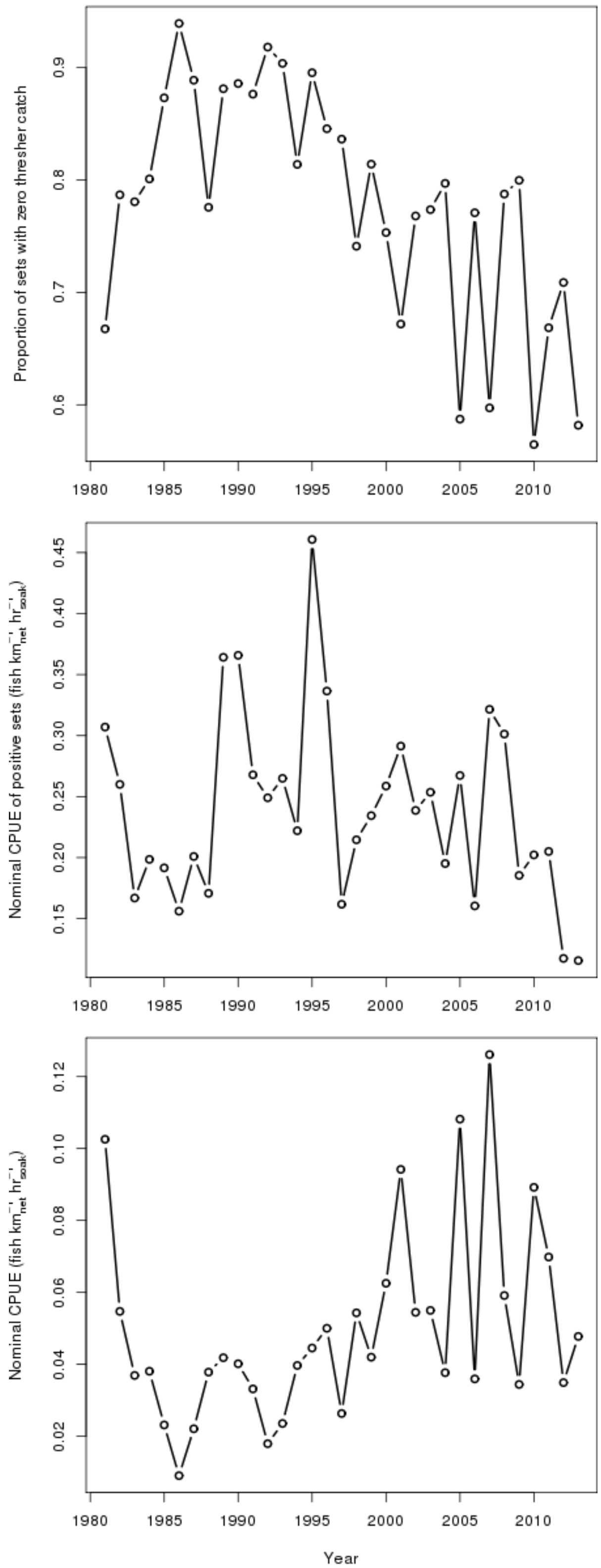
Model factors	**Df**	**Deviance**	**Residual Df**	**Residual Deviance**	**Pr(>Chi)**
Binomial: AIC = 10697					
Null			9698	11891	
Year	12	314.86	9686	11576	<2.2E-16
Latitude	4	13.00	9682	11563	0.0112
Season	2	258.04	9680	11305	<2.2E-16
Distance from shore	6	315.45	9674	10990	<2.2E-16
Decile rank of swordfish catch	9	235.57	9665	10754	<2.2E-16
Depth	10	105.03	9655	10649	<2.2E-16
Mesh	2	43.98	9653	10605	2.8E-10
Lognormal: AIC = 7342.6					
Null			2745	3149.8	
Year	12	80.12	2733	3069.7	3.3E-15
Latitude	4	44.09	2729	3025.6	9.2E-11
Season	2	12.61	2727	3013.0	5.3E-04
Distance from shore	6	461.32	2721	2551.7	<2.2E-16
Decile rank of swordfish catch	9	163.89	2712	2387.8	<2.2E-16
Depth	10	110.77	2702	2277.0	<2.2E-16
Mesh	2	24.69	2700	2252.3	3.7E-07

Table A.3. Estimated relative abundance index values, standard errors (SEs), and coefficients of variation (CVs) for three time periods: 1982 – 1984; 1992 – 2000; and 2001 – 2013 for the USA swordfish/shark drift gillnet fishery. The SEs and CVs were estimated with a jackknife procedure.

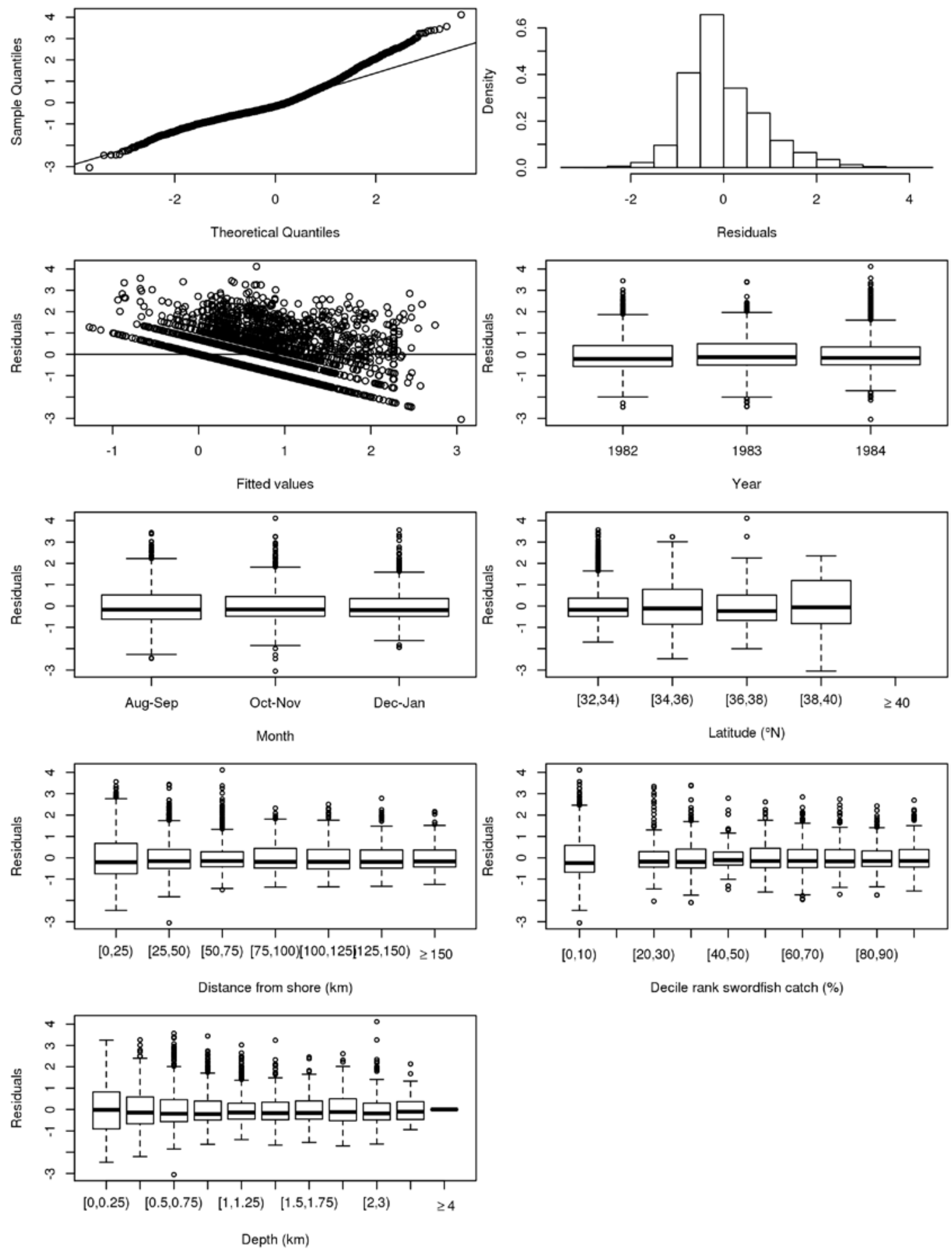
Year	Index	SE	CV
1982 – 1984			
1982	0.01229	0.00345	0.28035
1983	0.00921	0.00256	0.27814
1984	0.00763	0.00212	0.27842
1992 – 2000			
1992	0.00047	5.45E-05	0.11681
1993	0.00066	7.40E-05	0.11289
1994	0.00107	1.21E-04	0.11289
1995	0.00076	9.68E-05	0.12739
1996	0.00099	1.24E-04	0.12568
1997	0.00112	1.34E-04	0.11994
1998	0.00214	2.58E-04	0.12047
1999	0.00126	1.64E-04	0.12996
2000	0.00191	2.84E-04	0.14880
2001 – 2013			
2001	0.01269	0.00250	0.19702
2002	0.00631	0.00128	0.20242
2003	0.00575	0.00122	0.21192
2004	0.00518	0.00112	0.21691
2005	0.01830	0.00372	0.20352
2006	0.00687	0.00137	0.19910
2007	0.02289	0.00451	0.19697
2008	0.00685	0.00151	0.22096
2009	0.00391	8.79E-04	0.22504
2010	0.01745	0.00403	0.23111
2011	0.01148	0.00264	0.23021
2012	0.00711	0.00162	0.22832
2013	0.01244	0.00247	0.19884



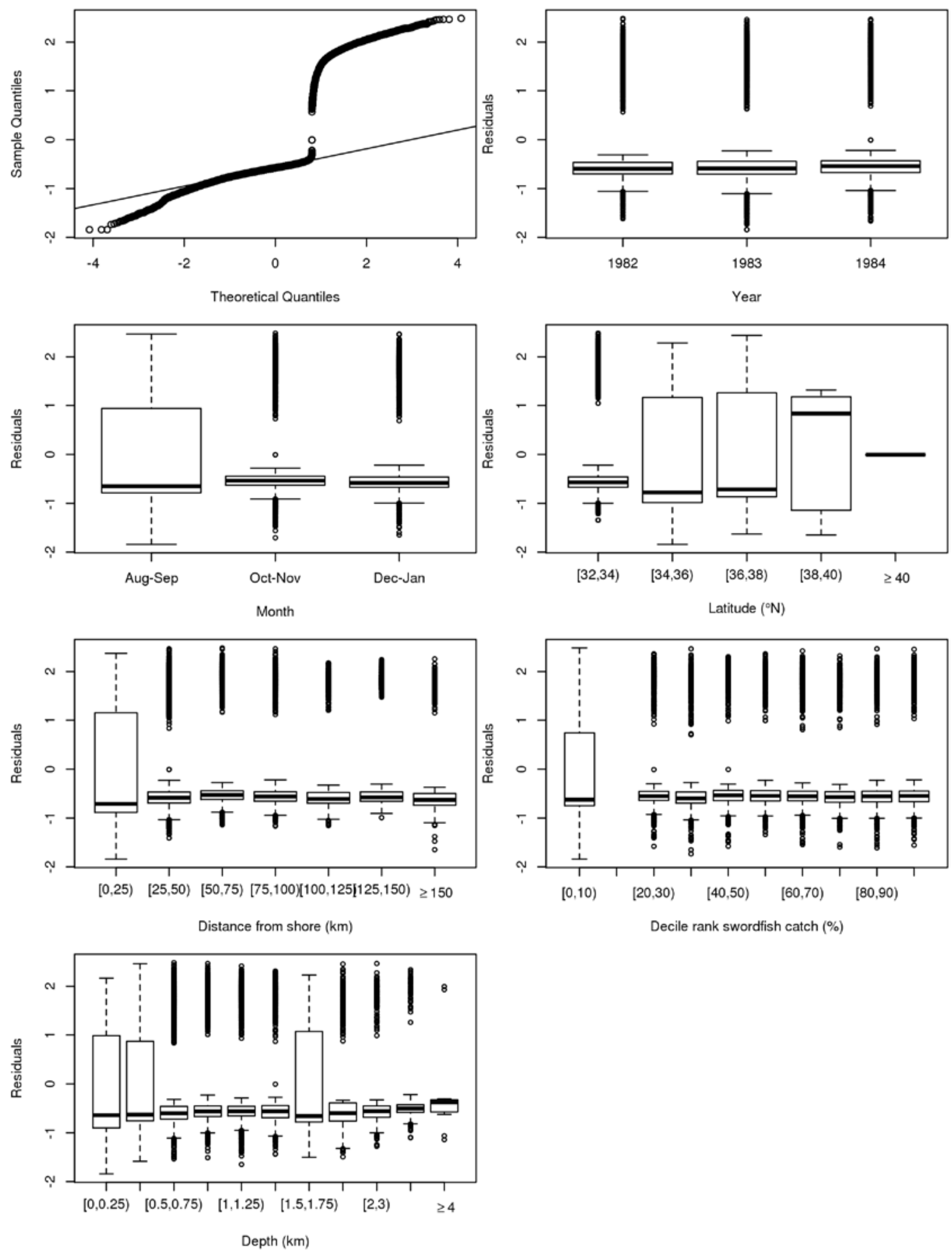
Appendix Figure A.1. Spatial distribution of sets (left) and common thresher shark catch (right) for the USA swordfish/shark drift gillnet fishery over three periods used for abundance indices.



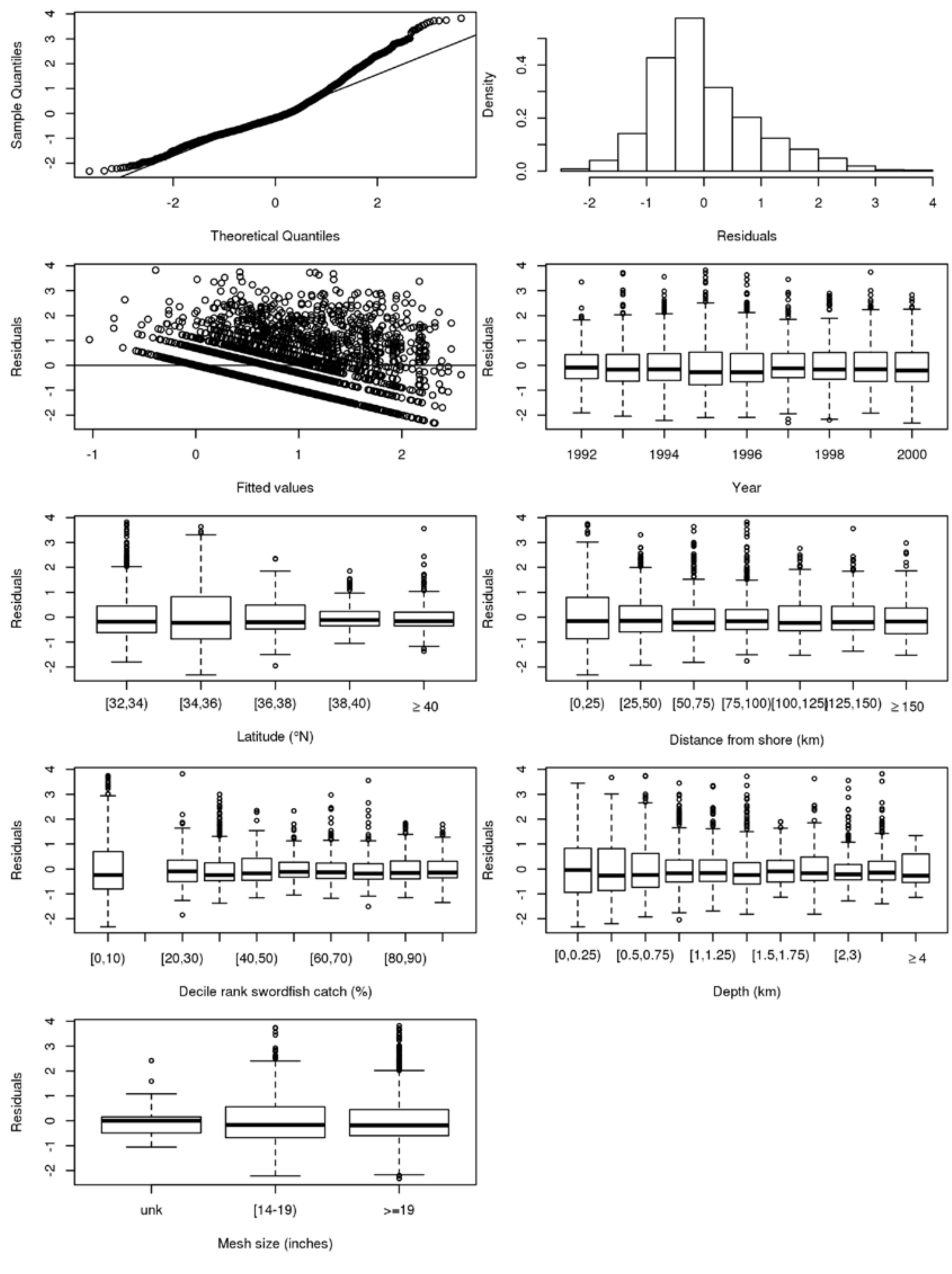
Appendix Figure A.2. Proportion of sets with zero thresher shark catch (upper), nominal catch-per-unit-effort (CPUE) of sets with positive thresher catch (middle), and overall nominal CPUE (lower) for common thresher sharks caught by the USA swordfish/shark drift gillnet fishery.



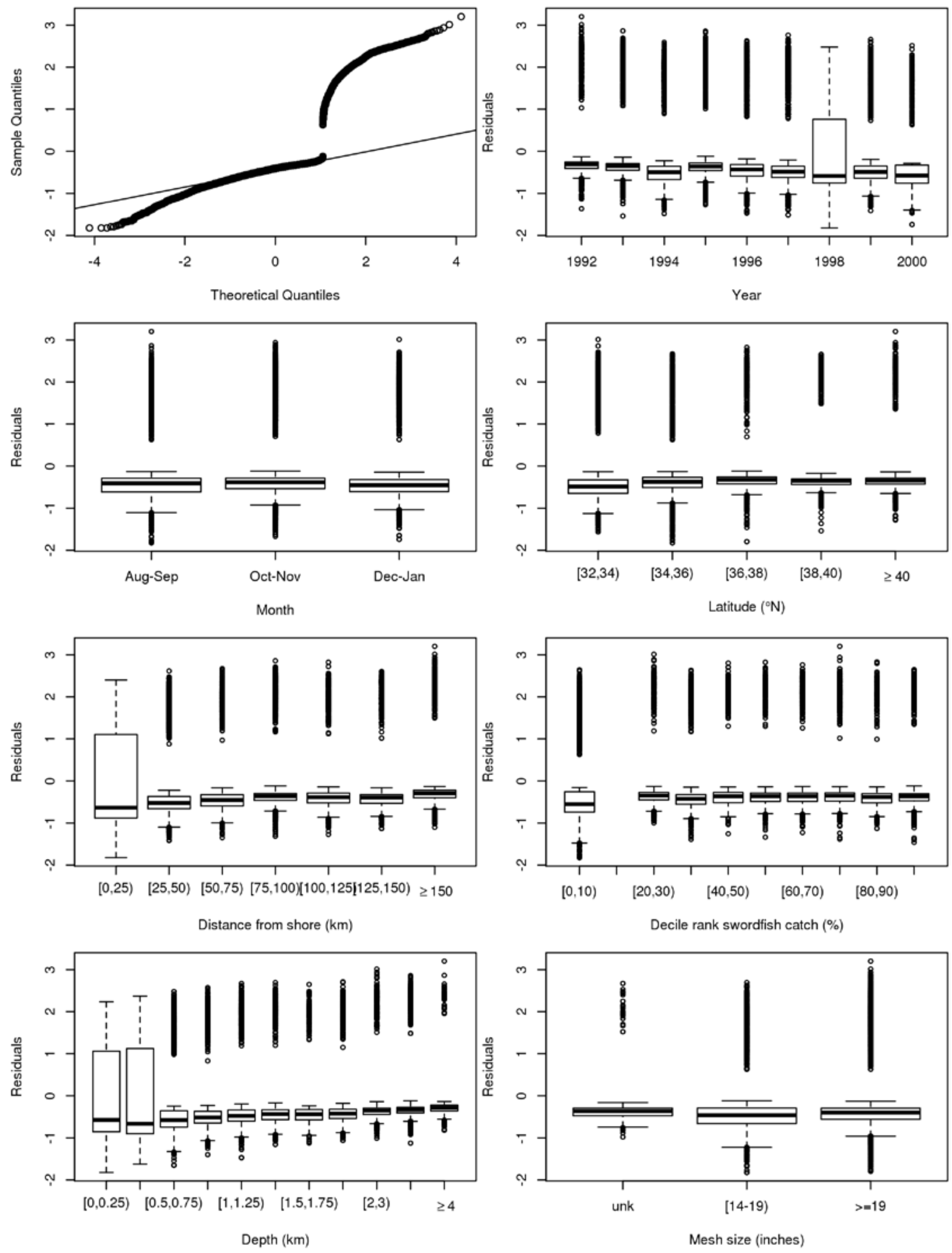
Appendix Figure A.3. Residual plots of the lognormal portion of the delta-lognormal model used to standardize the 1982 – 1984 common thresher shark abundance index for the USA swordfish/shark drift gillnet fishery.



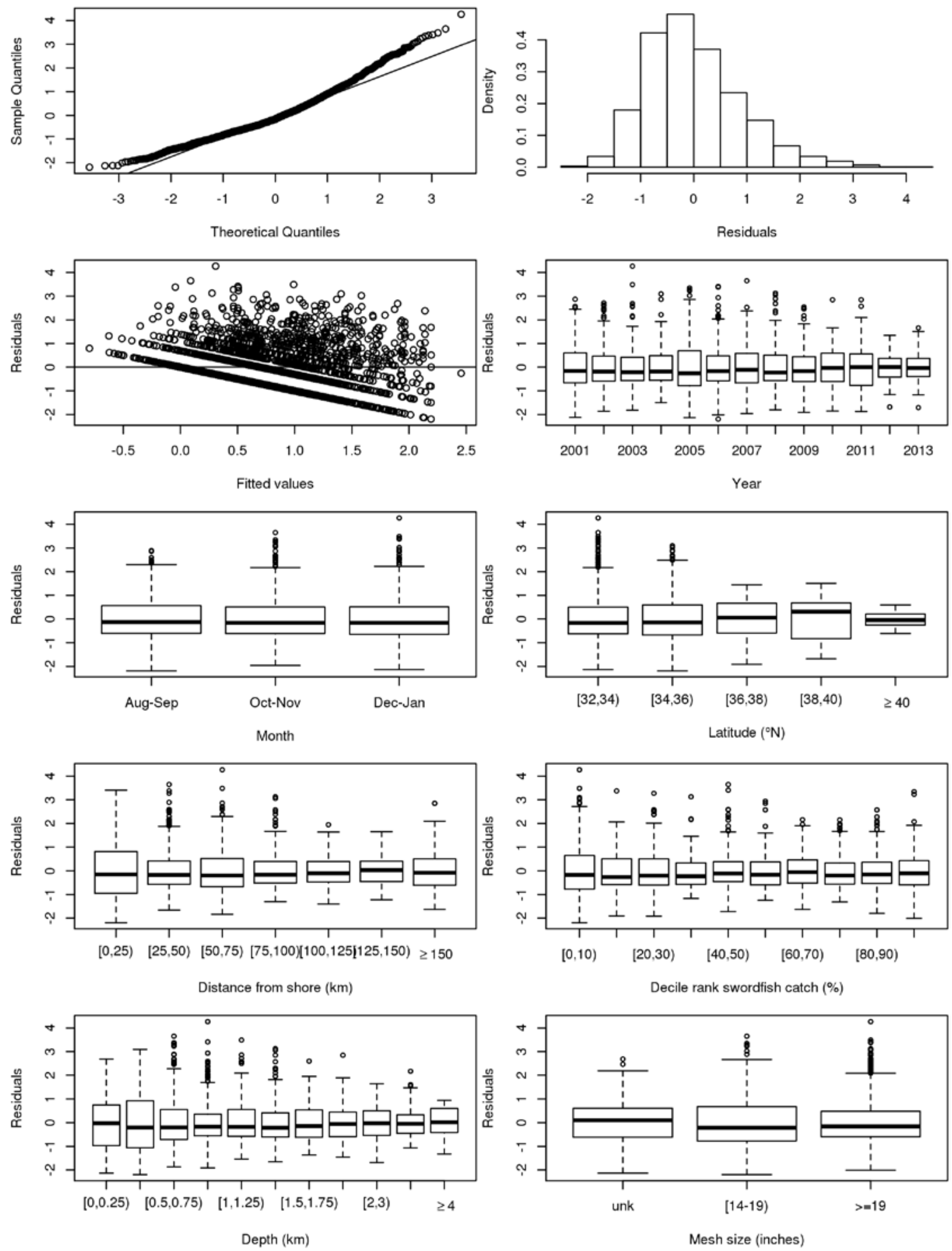
Appendix Figure A.4. Residual plots of the binomial portion of the delta-lognormal model used to standardize the 1982 – 1984 common thresher shark abundance index for the USA swordfish/shark drift gillnet fishery.



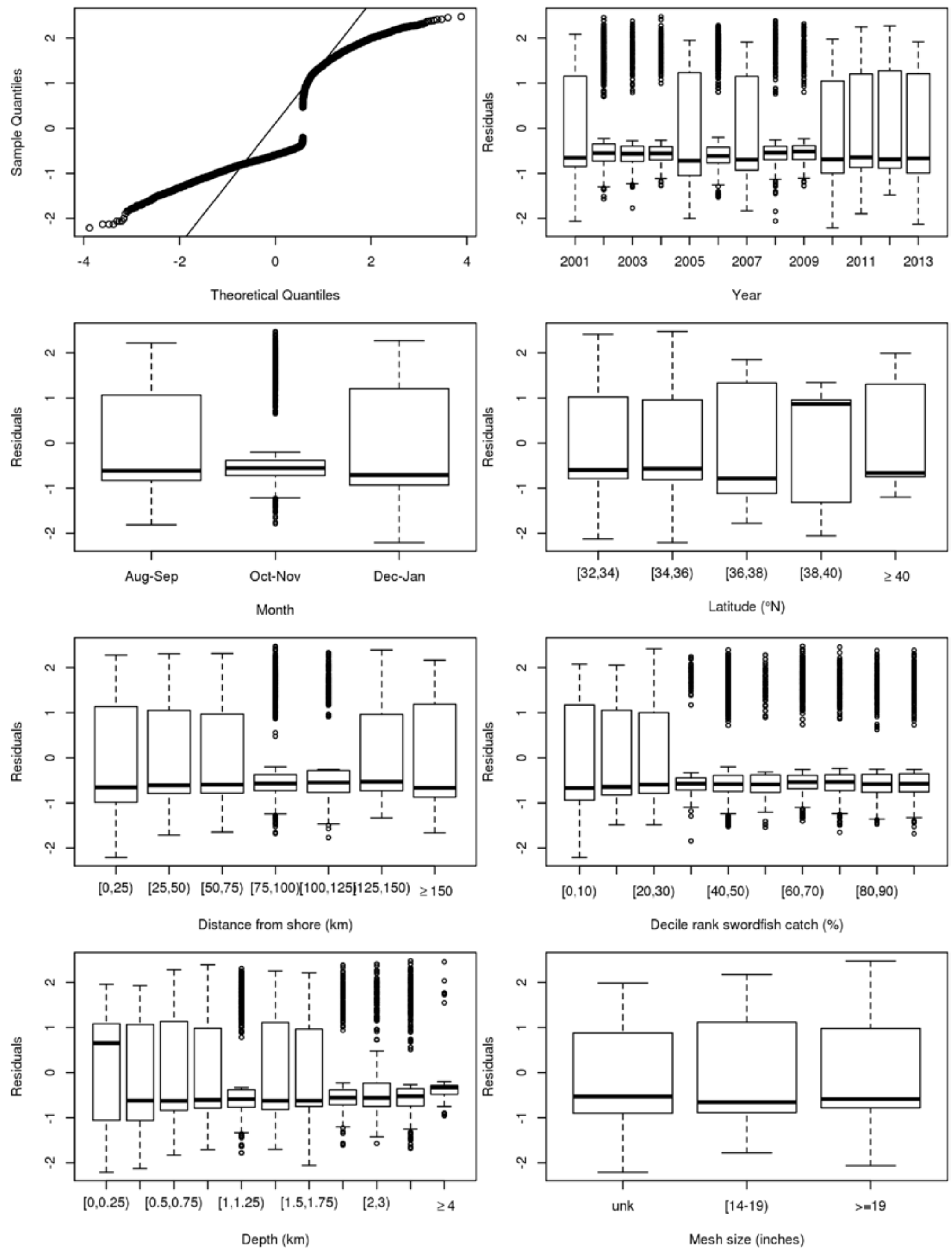
Appendix Figure A.5. Residual plots of the lognormal portion of the delta-lognormal model used to standardize the 1992 – 2000 common thresher shark abundance index for the USA swordfish/shark drift gillnet fishery.



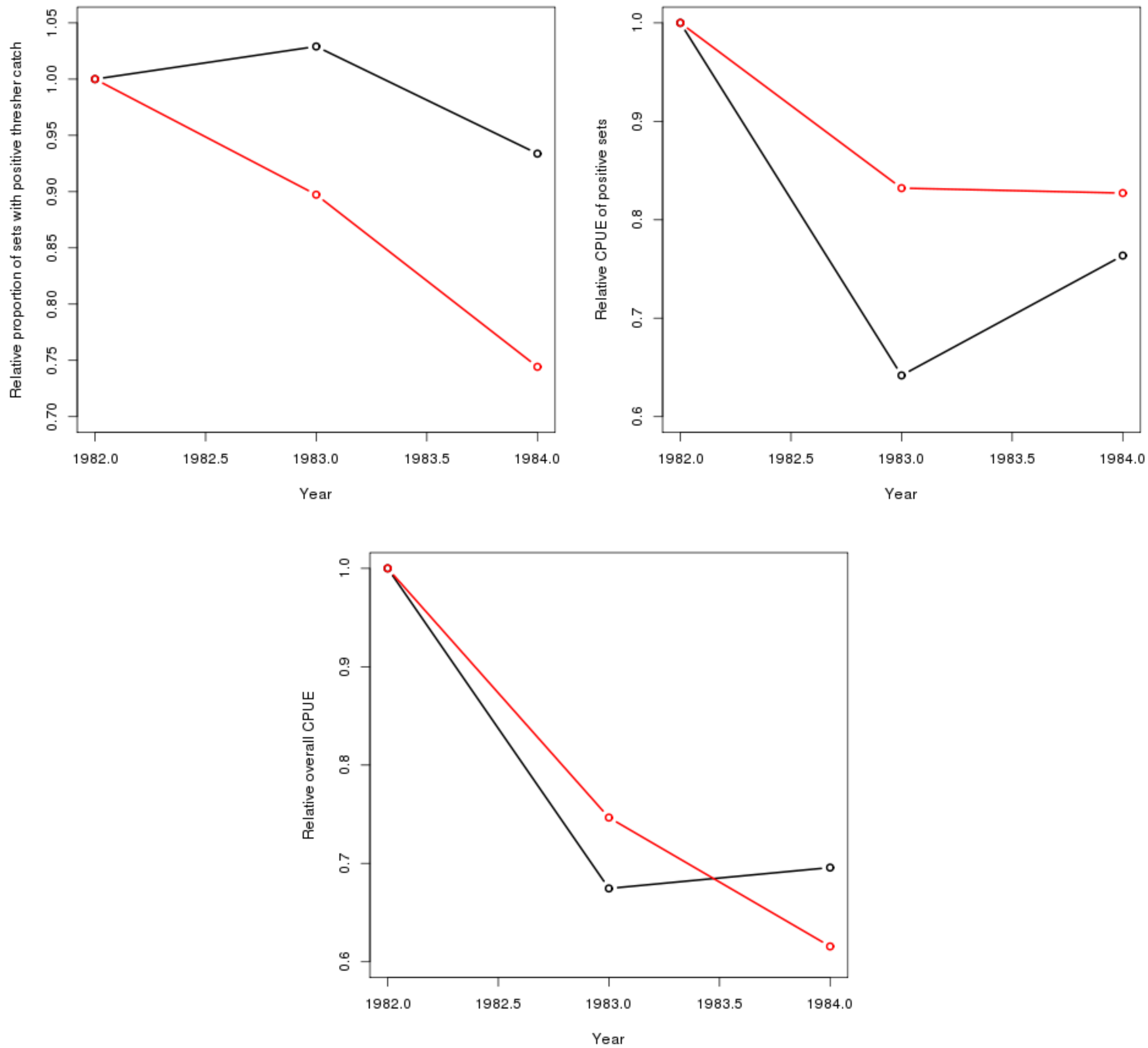
Appendix Figure A.6. Residual plots of the binomial portion of the delta-lognormal model used to standardize the 1992 – 2000 common thresher shark abundance index for the USA swordfish/shark drift gillnet fishery.



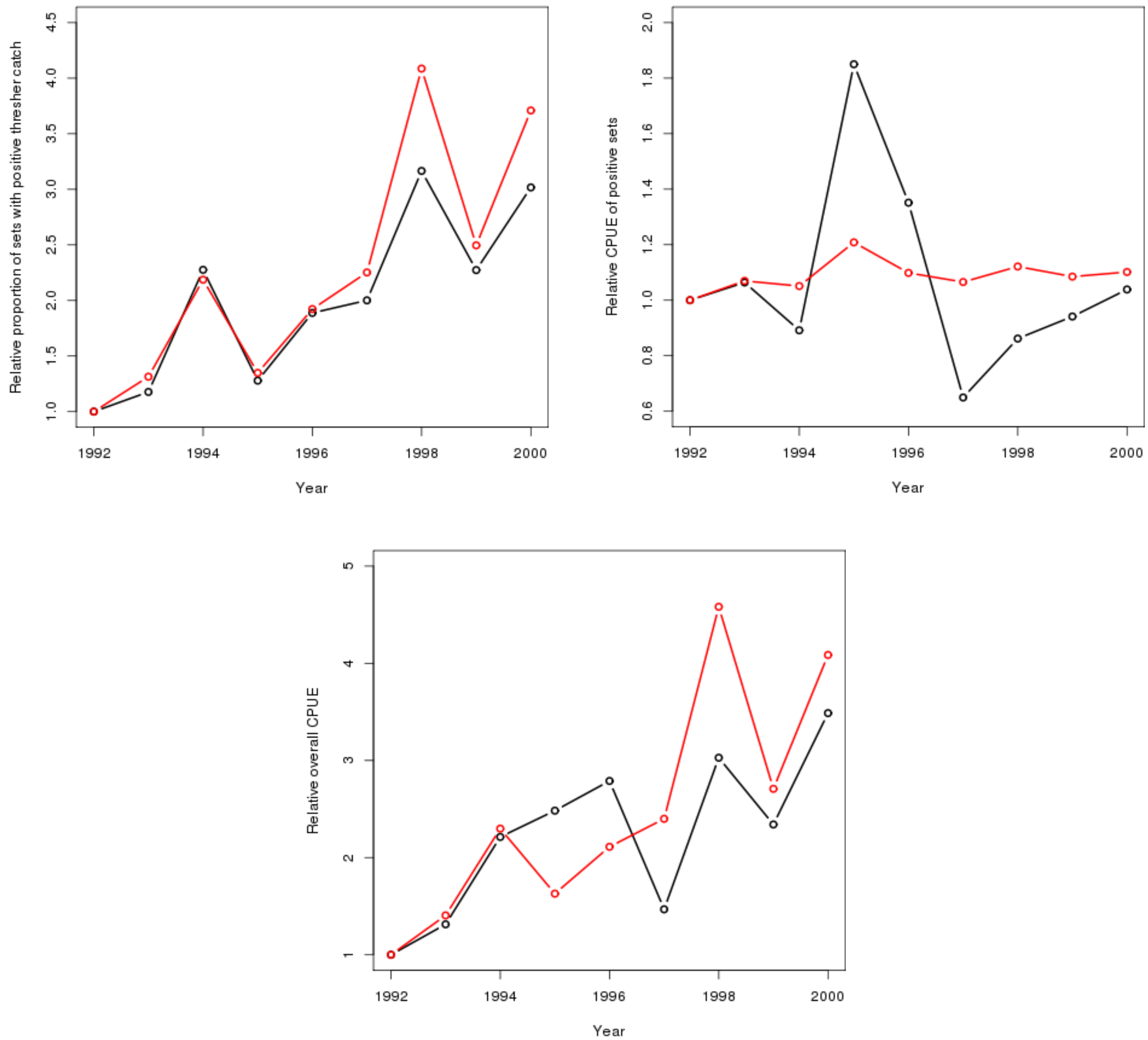
Appendix Figure A.7. Residual plots of the lognormal portion of the delta-lognormal model used to standardize the 2001 – 2013 common thresher shark abundance index for the USA swordfish/shark drift gillnet fishery.



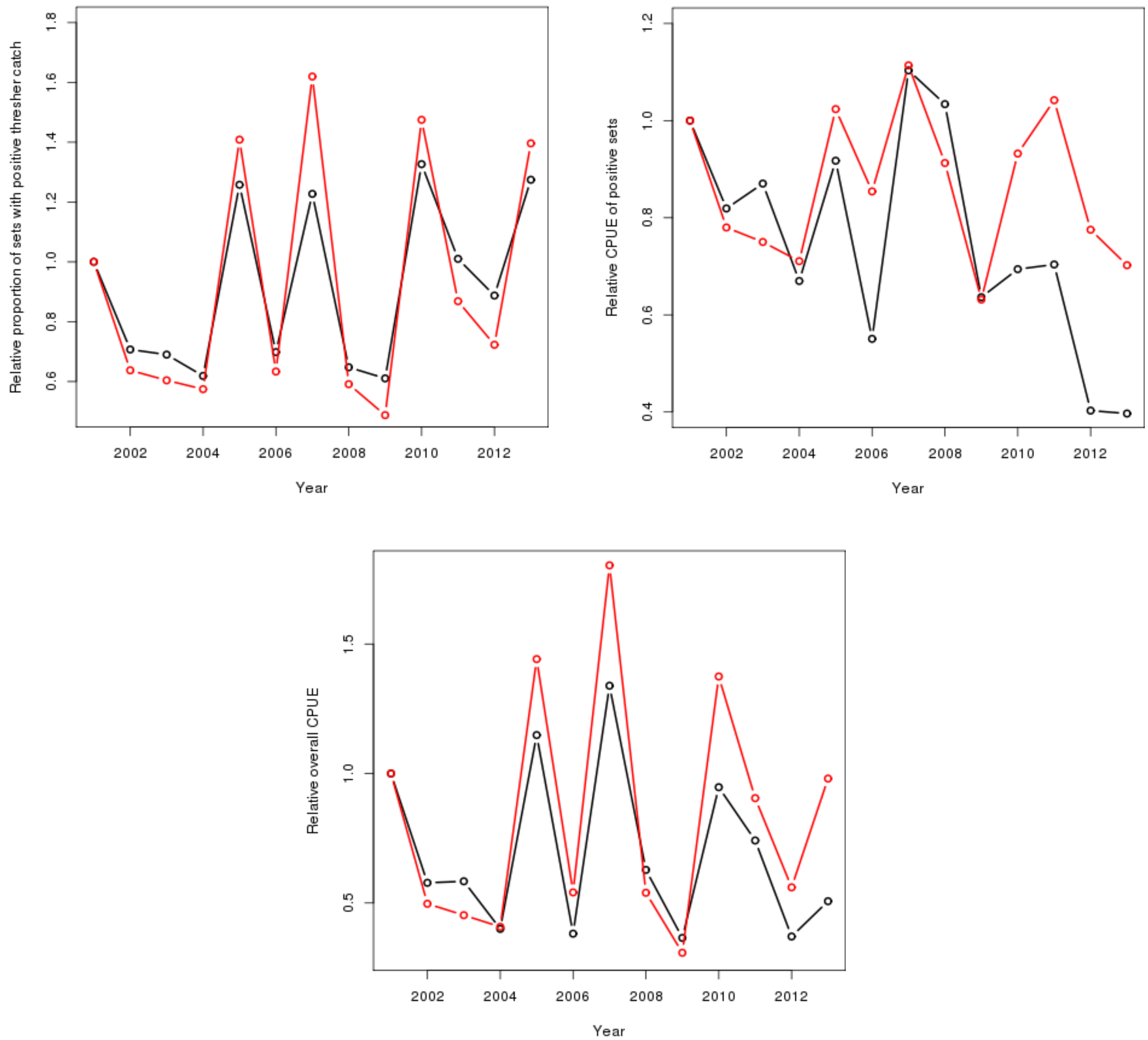
Appendix Figure A.8. Residual plots of the binomial portion of the delta-lognormal model used to standardize the 2001 – 2013 common thresher shark abundance index for the USA swordfish/shark drift gillnet fishery.



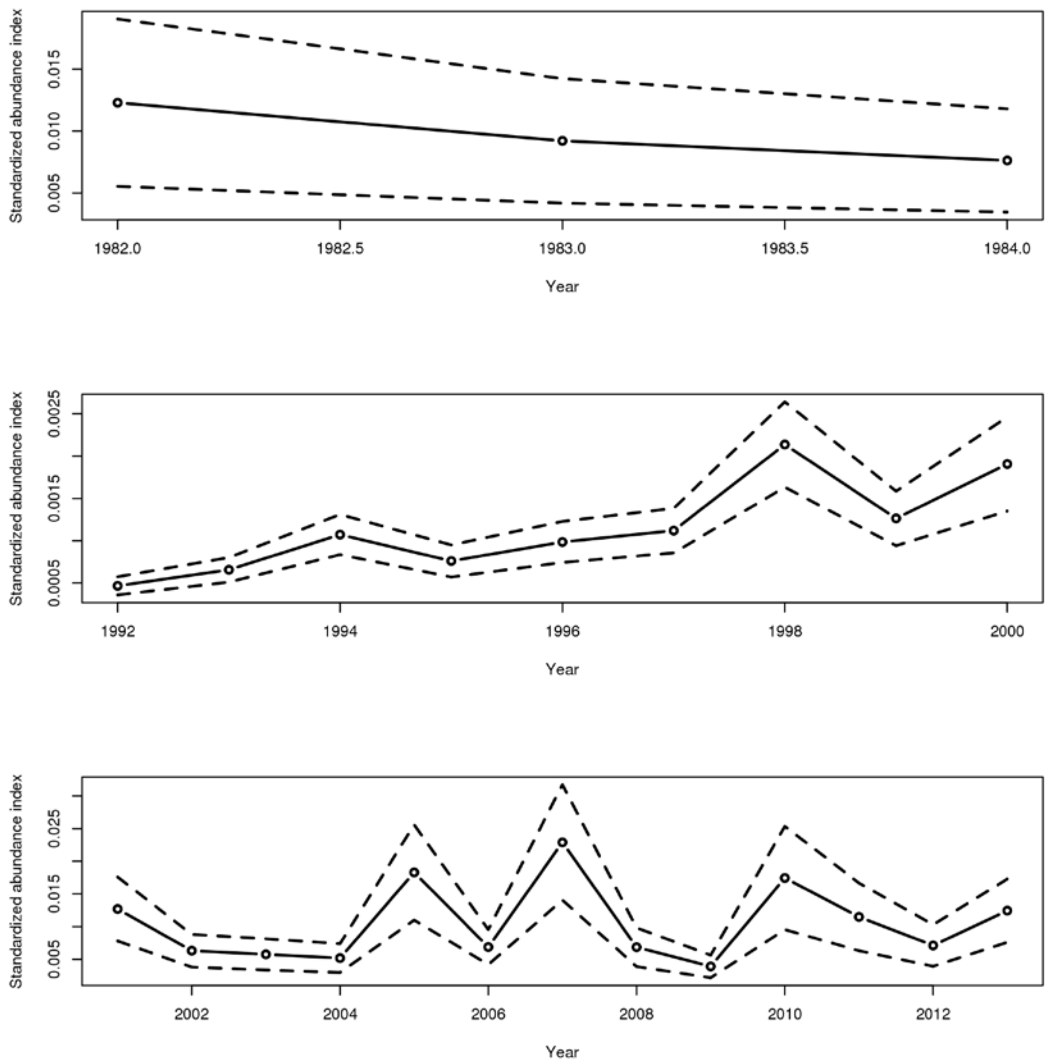
Appendix Figure A.9. Relative proportion of positive sets (upper left), CPUE of positive sets (upper right), and overall CPUE (lower) of nominal (black) and standardized (red) CPUE of the USA swordfish/shark drift gillnet fishery during 1982 – 1984. Indices are plotted relative to the value of the initial year.



Appendix Figure A.10. Relative proportion of positive sets (upper left), CPUE of positive sets (upper right), and overall CPUE (lower) of nominal (black) and standardized (red) CPUE of the USA swordfish/shark drift gillnet fishery during 1992 – 2000. Indices are plotted relative to the value of the initial year.



Appendix Figure A.11. Relative proportion of positive sets (upper left), CPUE of positive sets (upper right), and overall CPUE (lower) of nominal (black) and standardized (red) CPUE of the USA swordfish/shark drift gillnet fishery during 2001 – 2013. Indices are plotted relative to the value of the initial year.



Appendix Figure A.12. Standardized abundance indices of the USA swordfish/shark drift gillnet fishery during three periods: 1982 – 1984 (upper), 1992 – 2000 (middle), and 2001 – 2013 (lower). Dashed lines indicate 95% confidence intervals derived from jackknifing the data set.

APPENDIX B: Abundance indices for the USA nearshore set gillnet and small-mesh drift gillnet fishery

INTRODUCTION

A secondary USA commercial fishery that catches common thresher sharks is the nearshore set gillnet and small-mesh drift gillnet (USSN) fishery that target nearshore species like barracuda, white seabass, and halibut. The key differences between this fishery and the USA swordfish/shark drift gillnet (USDGN) fishery are that the USSN fishery uses nets with smaller mesh size (typically <10 inches) and operates in shallow, nearshore waters. Most of the catch and effort of the USSN fishery centers around the Southern California Bight but some parts of the fishery operates in nearshore areas as far north as around Mendocino, California (Fig. B.1).

The USSN does not target common thresher sharks but occasionally capture common thresher sharks as bycatch. The continental shelf of the Southern California Bight is a known nursery area for common thresher sharks along the USA West Coast and the USSN fishery therefore catches predominantly age-0 common thresher sharks (Cartamil et al. 2010). These abundance indices were therefore considered to be recruitment indices.

In 1994, the California Marine Resources Protection Act of 1990 began prohibiting all gillnets and trammel nets within 3 nm of the California mainland and within 1 nm (or waters <70 fathoms deep) of the Channel Islands. This resulted in the USSN fishery fishing in slightly deeper waters from 1994. In addition, data from 1981 - 1985 were not used because the USSN data were mixed with the USDGN data and could not be easily separated until after 1985, when the USDGN fishery moved out of the 75 nm zone due to regulations. Based on these changes, two indices representing different regulatory and operational periods were developed for the USSN fishery: Index 1: 1985 – 1993; and Index 2: 1994 – 2014.

Unlike the USDGN fishery, data from all four seasons were used in the indices from the USSN fishery. In addition, it was also not necessary to correct for the USSN fishery targeting swordfish instead of pelagic sharks because neither swordfish nor pelagic sharks were targets of the fishery.

MATERIALS AND METHODS

Data

The abundance indices were developed from set-by-set logbook data submitted by skippers of vessels in the USSN fishery after a mandatory logbook program was established in 1980, with the initial data collected in the 1981 – 1982 fishing season (Hanan et al. 1993). This was the same logbook program for the USDGN fishery. Data collected by the logbooks included catch (numbers of fish) by species, date, mesh size, net length, hours soaked, set number, and geographical position. Geographical positions were entered as CDFG block numbers (predominantly 10 min by 10 min squares), which were subsequently converted to latitudes and longitudes based on the center of the blocks.

Preliminary examination of the data indicated that two stages of filtering were required before the data could be used for developing abundance indices. The number of sets in the data after each filtering stage is summarized in Table B.1 and the spatial distribution of the sets and catch can be seen in Fig. A.1. The two filtering stages were:

1. Identifying USSN sets

The original data set included data from both the USSN and USDGN fisheries. The logbook data were therefore filtered to select for data where gear type was identified as "set net", and target species were not identified as swordfish or shark, and mesh size was ≤10 inches or unspecified.

2. Identifying abnormal fishing operations

The majority of fishing operations for the USSN fishery used nets ranging from 250 to 1,000 fathoms long and had soak times of one or two days. However, abnormal fishing operations could result from nets being left in the water, and experimental trips using shorter nets and/or soak times. Sets with abnormal fishing operations or misreported information were identified and removed in the second filtering stage because it is inappropriate to use data from these abnormal fishing operations. Abnormal sets were identified based on fishery knowledge. As a result, sets that recorded missing or abnormal soak times (<6 or >48 hours), net lengths (<100 or >2000 m), mesh size (<2 or >10 inches), locations (latitude: <32 or >40°N; distance from shore: >20 km), and depth (>100 m).

The logbook data were divided into strata based on available factors. Season was categorized as four trimonthly periods ([Feb, Apr], [May, Jul], [Aug, Oct], [Nov, Dec]). Six areas were defined based on the latitude ([32, 33), [33, 34), [34, 35), [35, 36), [36,37), and [37,40] °N). Other factors included water depth (4 levels: [0, 20), [20, 40), [40, 80), and [80, 100] m), distance from shore (4 levels: [0, 5), [5, 10), [10, 15), and [15, 20] km), and mesh size (5 levels: unknown, [1, 3), [3, 6), [6, 8), and [8,10] inches).

Models

Delta-lognormal models (Lo et al. 1992) were used to standardize the catch per unit effort (CPUE) to obtain the abundance indices used in the stock assessment because the data set contained a large proportion of sets with zero thresher catch (Fig. A.2). Catch was defined as the sum of all kept and discarded common thresher sharks in a single set, and effort was defined as the product of the length of the net (km) and soak time (days). Delta-lognormal models assumes that the proportion of sets with positive catch have a binomial error structure and is modeled by a GLM with a logit link function, and the catch rate of sets with positive catch has a lognormal error distribution and is modeled by a lognormal GLM. The standardized index was the product of the back-transformed marginal year effects (Searle 1980) of these two components, with a correction for the bias in the lognormal back transformation. Estimates of variance were obtained by jackknifing the data set, using a modified version of delta_glm_1-7-2 function (E. J. Dick, pers. comm.) in R (function was modified to allow for different factors for the binomial and lognormal functions).

A forward-backward stepwise model selection process, with AIC as the selection criteria, was used to determine the set of factors that explained the catch of common thresher sharks in the logbook data. The binomial and lognormal models for each time period were selected independently.

RESULTS AND DISCUSSION

Based on the stepwise model selection process, the final delta-lognormal models for each time period were:

<u>1985 – 1993</u>
Binom: $\text{logit}(\pi) \sim \text{year} + \text{lat} + \text{season} + \text{distance} + \text{mesh} + \text{offset}[\log(\text{eff})] + \varepsilon$
Lognormal: $\log(\text{catch}) \sim \text{year} + \text{lat} + \text{distance} + \text{depth} + \text{mesh} + \text{offset}[\log(\text{eff})] + \varepsilon$

<u>1992 – 2000</u>
Binom: $\text{logit}(\pi) \sim \text{year} + \text{lat} + \text{season} + \text{depth} + \text{mesh} + \text{offset}[\log(\text{eff})] + \varepsilon$
Lognormal: $\log(\text{catch}) \sim \text{year} + \text{lat} + \text{depth} + \text{mesh} + \text{offset}[\log(\text{eff})] + \varepsilon$

where π was the probability of a set having positive common thresher shark catch, and the random error structures of the binomial and lognormal models were assumed to be Binom(n, π) and N(0, σ) respectively. Deviance tables for both time periods are found in Table B.2. No first-order interactions were included in the final model selection process because abundance indices with or without first-order interactions were highly similar.

Model diagnostics indicated adequate performance of the lognormal and binomial models for all three abundance indices (Fig. B.3 – B.6). For both time periods, the lognormal residuals were slightly skewed because the lognormal models had problems fitting sets with small numbers of fish. However, the mean predicted values of both the lognormal and binomial component models were highly representative of the observed values after aggregation into spatial and temporal bins.

In the first time period (1985 – 1993), a large spike in the nominal index was substantially reduced by the standardization, resulting in an index that gradually decreased to a minimum in 1989 before gradually increasing (Fig. B.7). The standardized abundance index for the second time period (1994 – 2014) indicated that the common thresher shark recruitment increased substantially during this period, albeit with substantial variability (Fig. B.8). The lognormal model reduced the variability apparent in the CPUE of positive sets but the variability in the binomial component was not visibly reduced. The jackknife procedure resulted in coefficients of variation (CVs) that were relatively high (Table B.3 and Fig. B.9).

Appendix Table B.1. Amount of data (number of sets) in the logbook data set before and after two stages of filtering for the USA nearshore set net fishery.

Period	**Number of sets prior to filtering**	**Number of sets after stage 1 filtering**	**Number of sets after stage 2 filtering**
1985 – 1993	192166	124542	68045
1994 – 2014	99174	62474	33680

Appendix Table B.2. Deviance analysis of explanatory variables in delta-lognormal models for common thresher shark catch rates of USA nearshore set net fishery for two time periods: 1) 1985 – 1993; and 2) 1994 – 2014.

1985 - 1993

Model factors	**Df**	**Deviance**	**Residual Df**	**Residual Deviance**	**Pr(>Chi)**
Binomial: AIC = 20812					
Null			68044	23752	
Year	8	58.98	68036	23694	7.38E-10
Latitude	5	1574.51	68031	22119	<2.2E-16
Season	3	1027.70	68028	21091	<2.2E-16
Distance from shore	3	44.72	68025	21047	1.06E-09
Mesh	4	282.50	68021	20764	<2.2E-16
Lognormal: AIC = 8113					
Null			2851	3316.0	
Year	8	113.22	2843	3202.8	<2.2E-16
Latitude	5	156.94	2838	3045.9	<2.2E-16
Distance from shore	3	71.74	2835	2974.1	1.67E-15
Depth	3	13.36	2832	2960.8	3.86E-03
Mesh	4	139.13	2828	2821.6	<2.2E-16

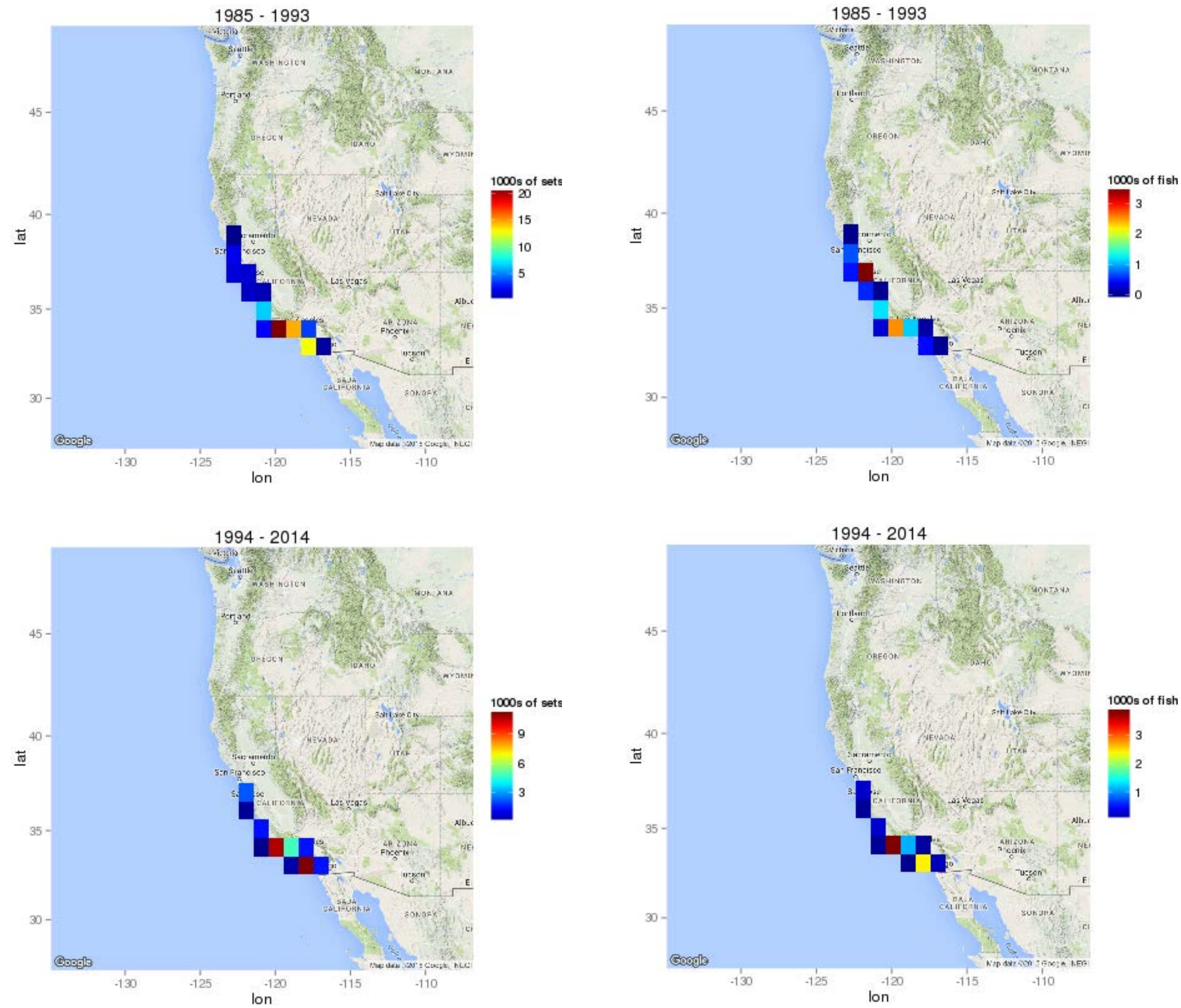
Appendix Table B.2. Continued.

1994 - 2014

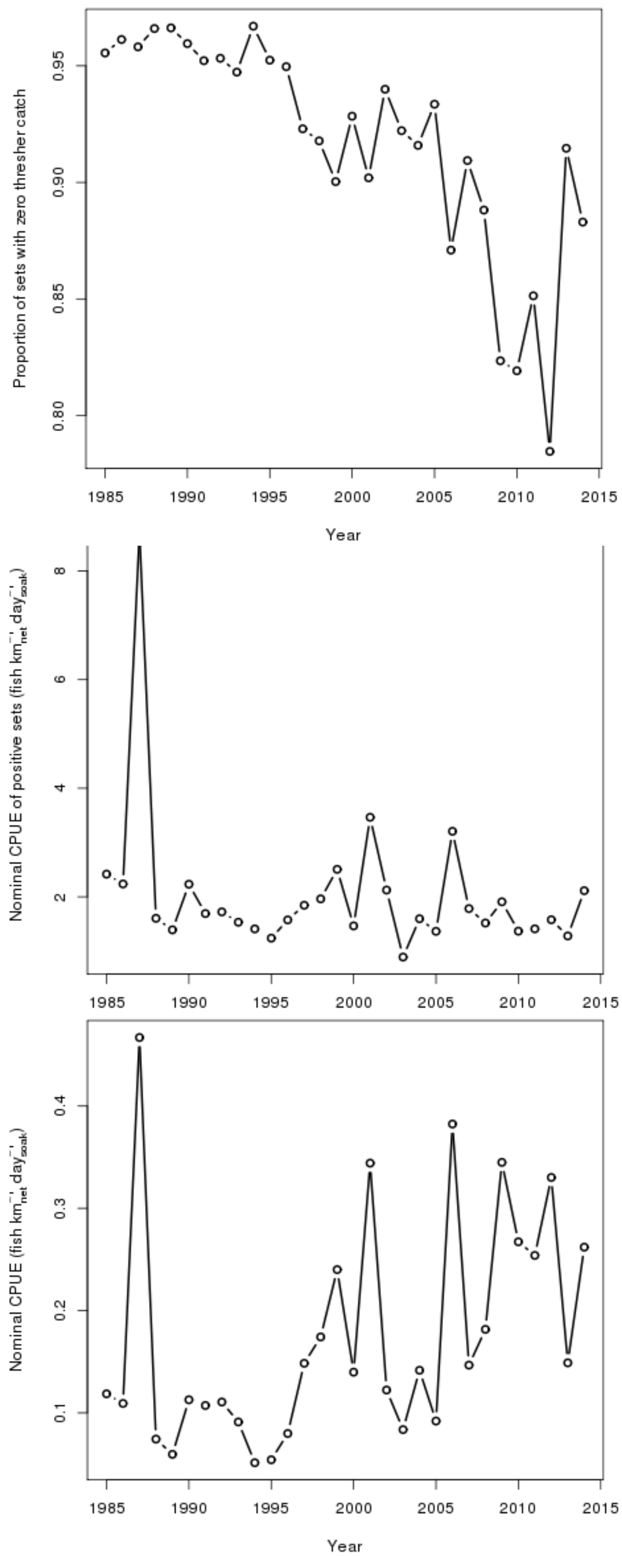
Model factors	Df	Deviance	Residual Df	Residual Deviance	Pr(>Chi)
Binomial: AIC = 18684					
Null			33679	21582	
Year	20	741.31	33659	20841	<2.2E-16
Latitude	5	464.32	33654	20377	<2.2E-16
Season	3	917.66	33651	19459	<2.2E-16
Depth	3	251.24	33648	19208	<2.2E-16
Mesh	4	595.40	33644	18612	<2.2E-16
Lognormal: AIC = 8807					
Null			3077	3850.9	
Year	20	138.38	3057	3712.6	<2.2E-16
Latitude	5	124.80	3052	3587.8	<2.2E-16
Depth	3	165.85	3049	3421.9	<2.2E-16
Mesh	3	338.23	3046	3083.7	<2.2E-16

Table B.3. Estimated relative abundance index values, standard errors (SEs), and coefficients of variation (CVs) for two time periods: 1985 – 1993; and 1994 – 2014 for the USA nearshore set net fishery. The SEs and CVs were estimated with a jackknife procedure.

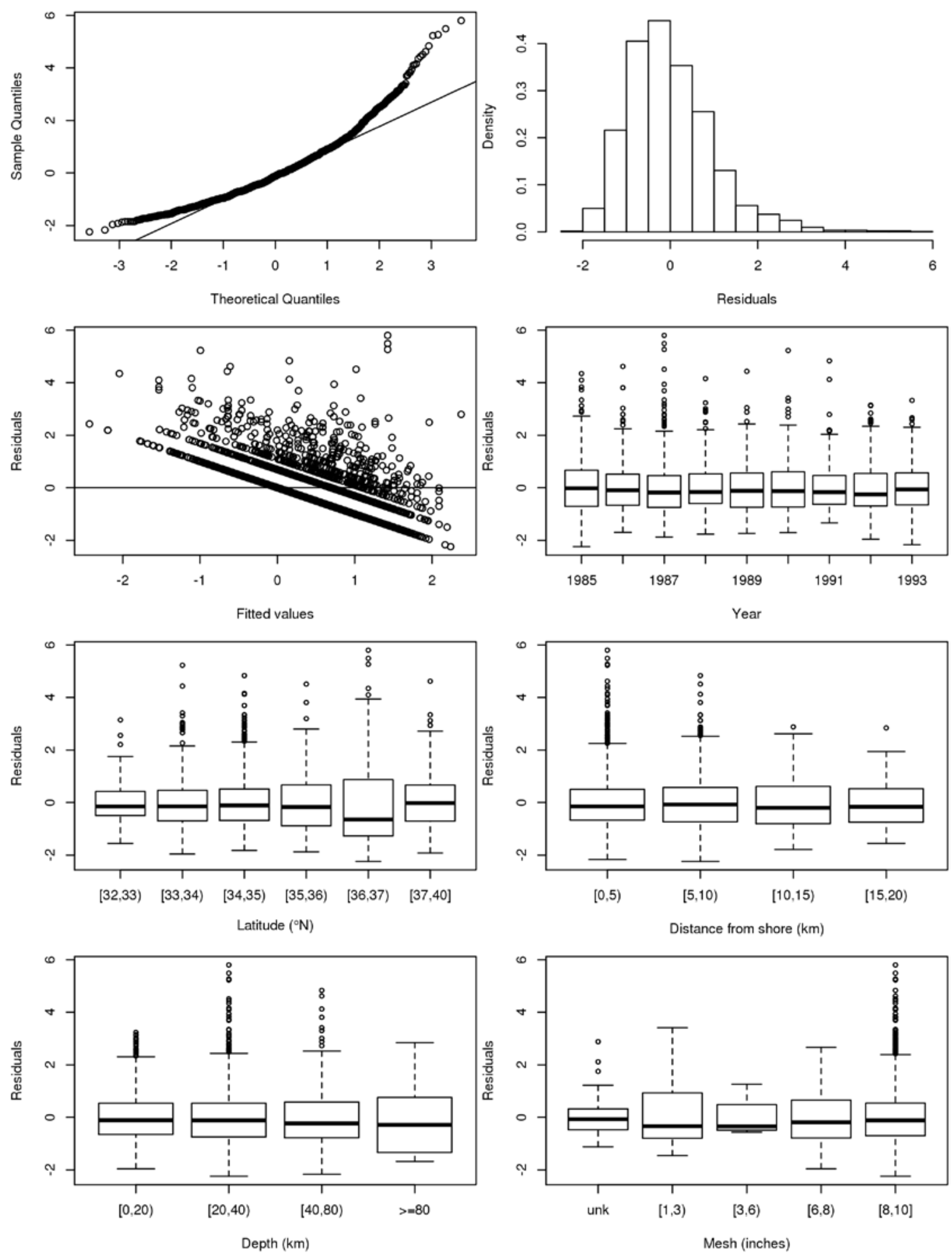
Year	Index	SE	CV
1985 – 1993			
1985	0.07149	0.01590	0.22246
1986	0.05076	0.01117	0.22000
1987	0.07998	0.01852	0.23149
1988	0.06265	0.01442	0.23024
1989	0.04039	0.00931	0.23056
1990	0.07087	0.01689	0.23840
1991	0.05103	0.01198	0.23477
1992	0.06788	0.01643	0.24198
1993	0.08320	0.01919	0.23061
1994 – 2014			
1994	0.20827	0.05303	0.25464
1995	0.20266	0.04715	0.23268
1996	0.29486	0.06484	0.21991
1997	0.45911	0.09166	0.19964
1998	0.49911	0.10357	0.20750
1999	0.55780	0.10615	0.19030
2000	0.33207	0.06748	0.20322
2001	0.69024	0.14693	0.21287
2002	0.38927	0.08773	0.22537
2003	0.22220	0.04553	0.20489
2004	0.29735	0.06158	0.20710
2005	0.24872	0.05692	0.22886
2006	1.00752	0.19371	0.19227
2007	0.69005	0.14078	0.20402
2008	0.38999	0.08275	0.21220
2009	0.69659	0.13596	0.19518
2010	0.76876	0.15233	0.19815
2011	0.51435	0.10836	0.21067
2012	0.72856	0.14386	0.19746
2013	0.21324	0.05124	0.24029
2014	0.81005	0.33390	0.41220



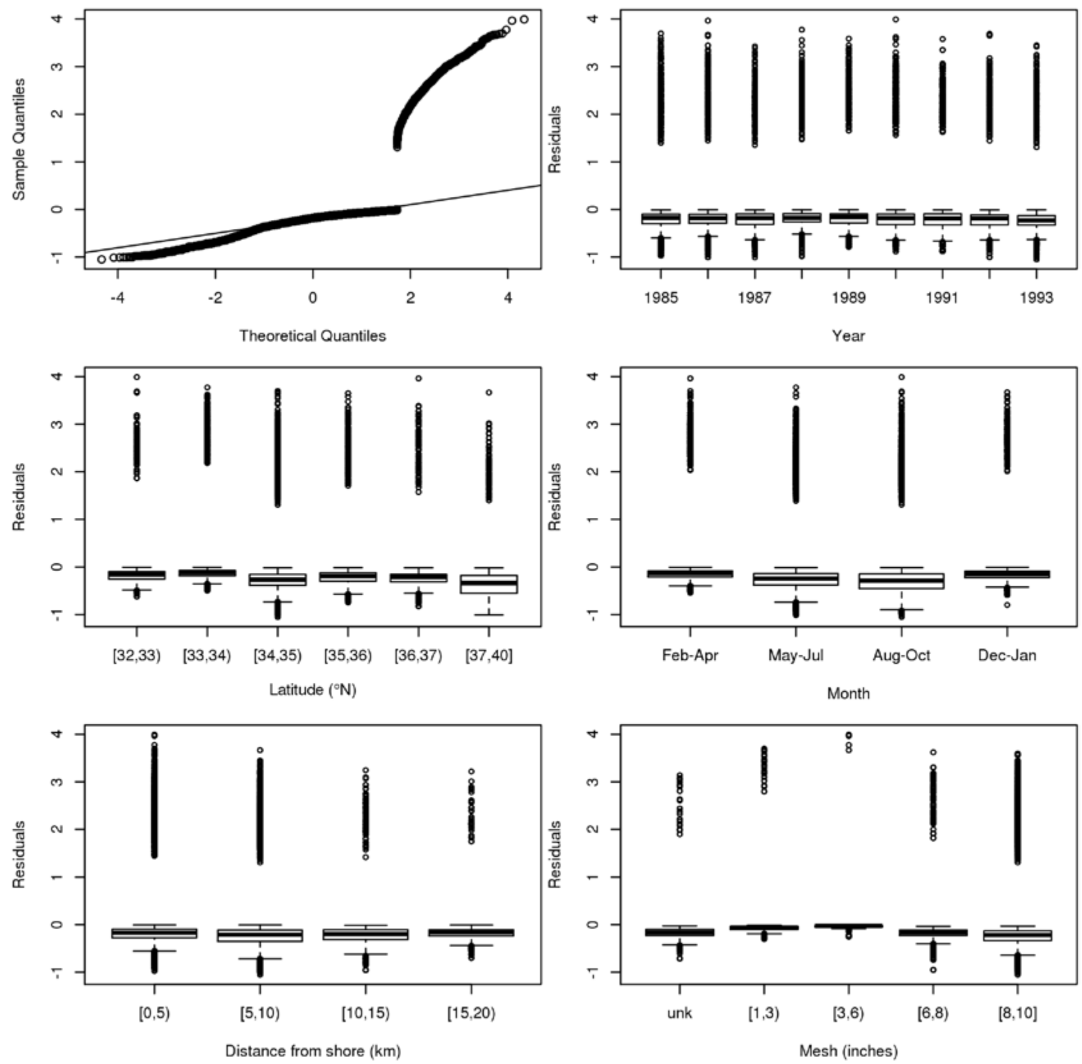
Appendix Figure B.1. Spatial distribution of sets (left) and common thresher shark catch (right) for the USSN fishery over three periods used for abundance indices.



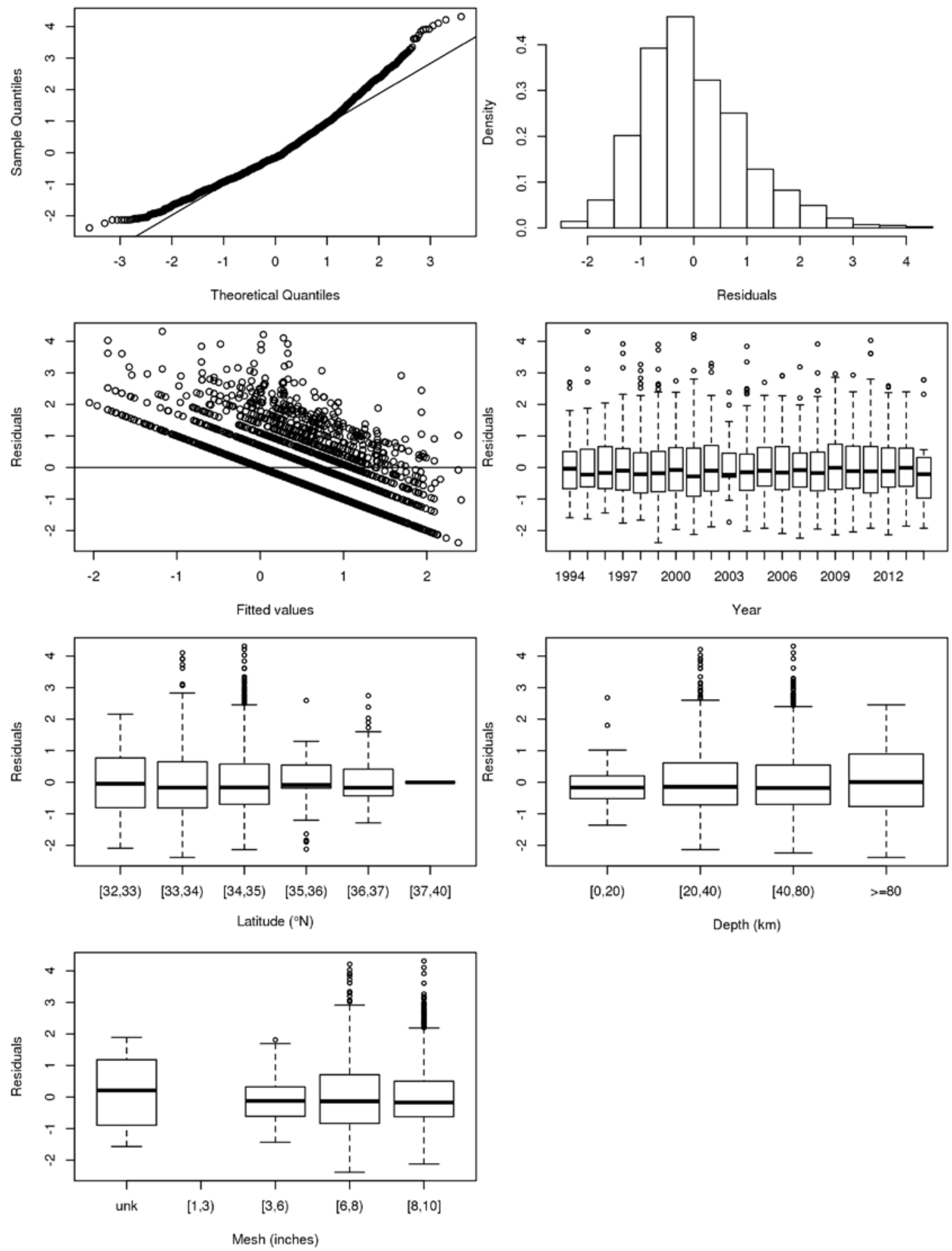
Appendix Figure B.2. Proportion of sets with zero thresher shark catch (upper), nominal catch-per-unit-effort (CPUE) of sets with positive thresher catch (middle), and overall nominal CPUE (lower) for common thresher sharks caught by the USSN fishery.



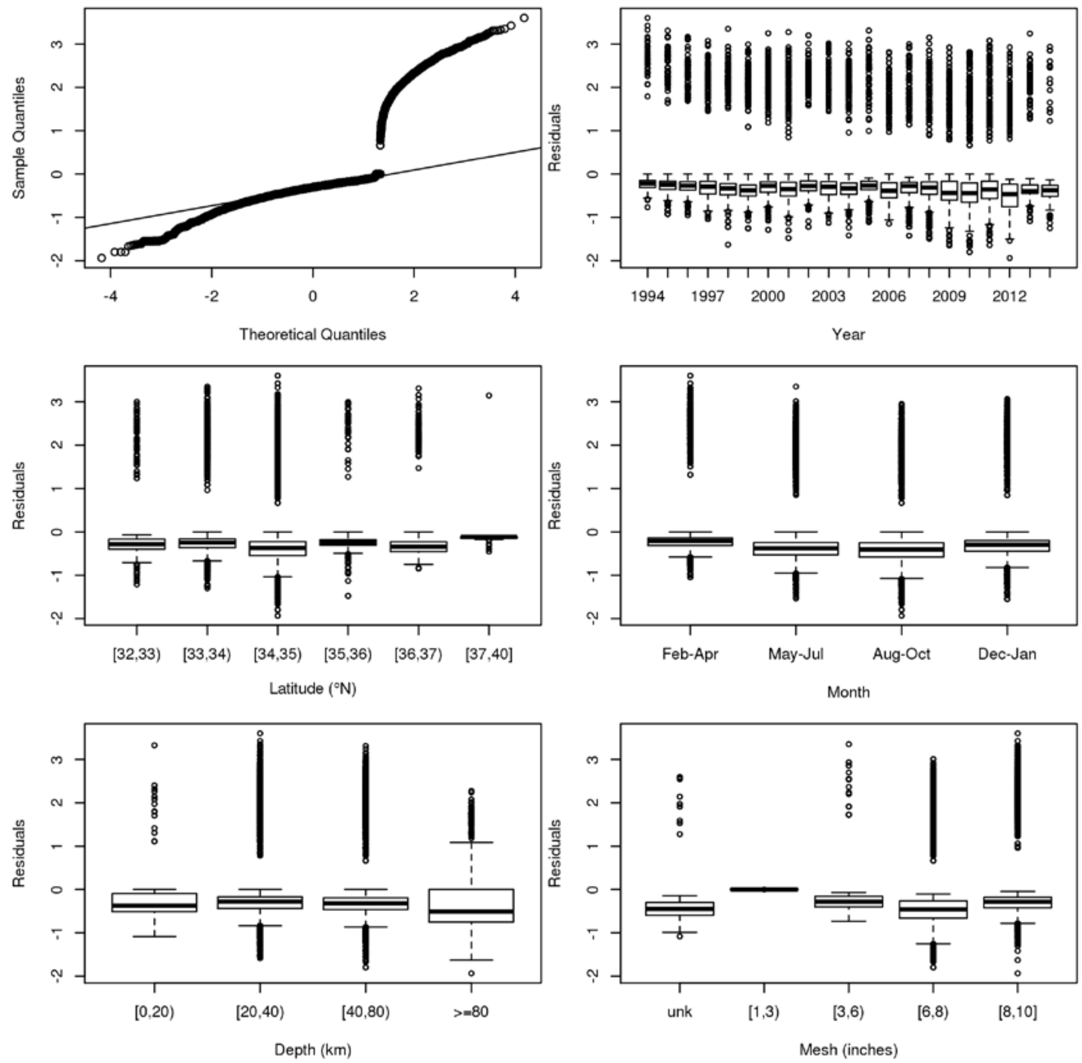
Appendix Figure B.3. Residual plots of the lognormal portion of the delta-lognormal model used to standardize the 1985 – 1993 common thresher shark abundance index for the USSN fishery.



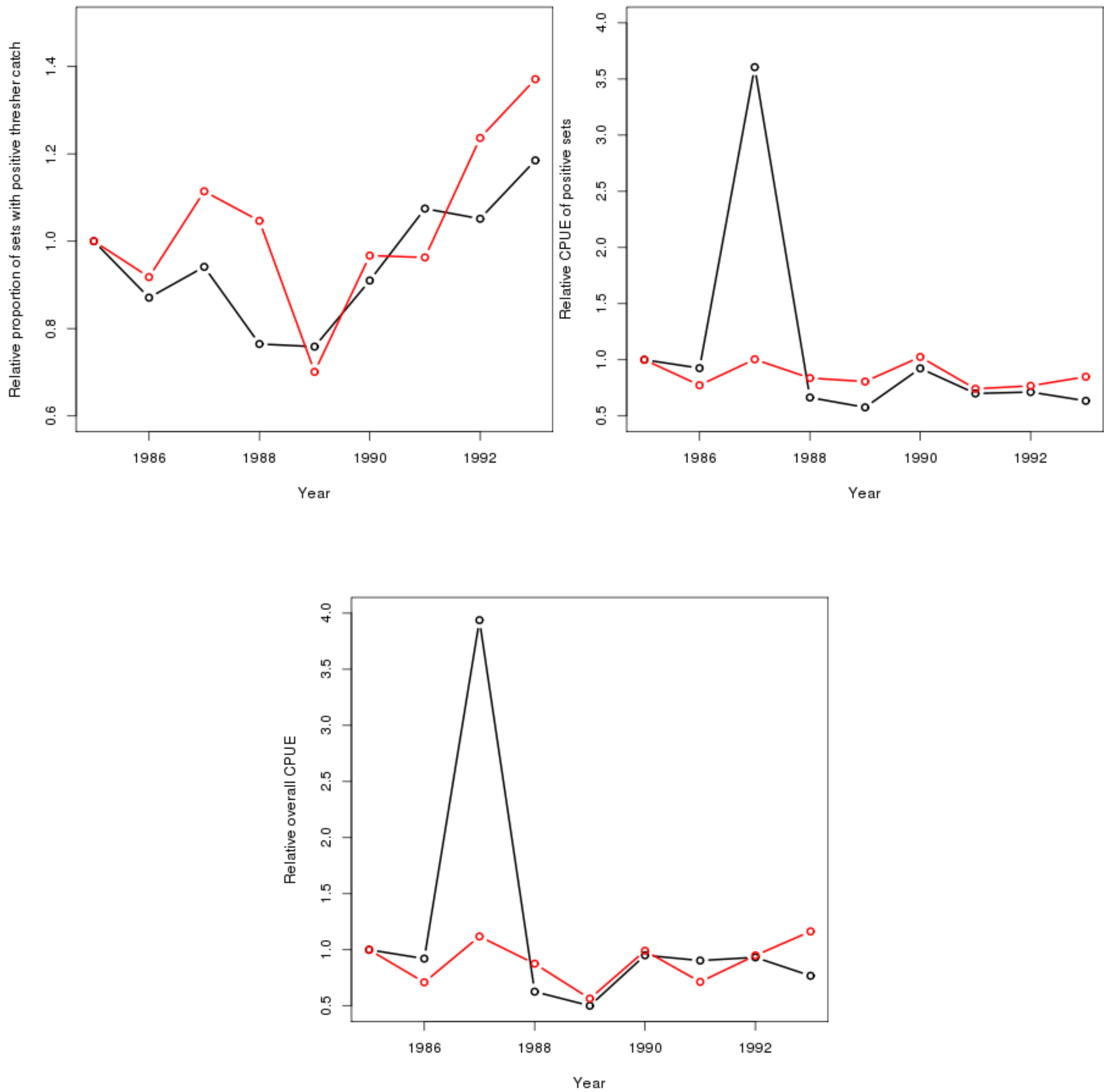
Appendix Figure B.4. Residual plots of the binomial portion of the delta-lognormal model used to standardize the 1985 – 1993 common thresher shark abundance index for the USSN fishery.



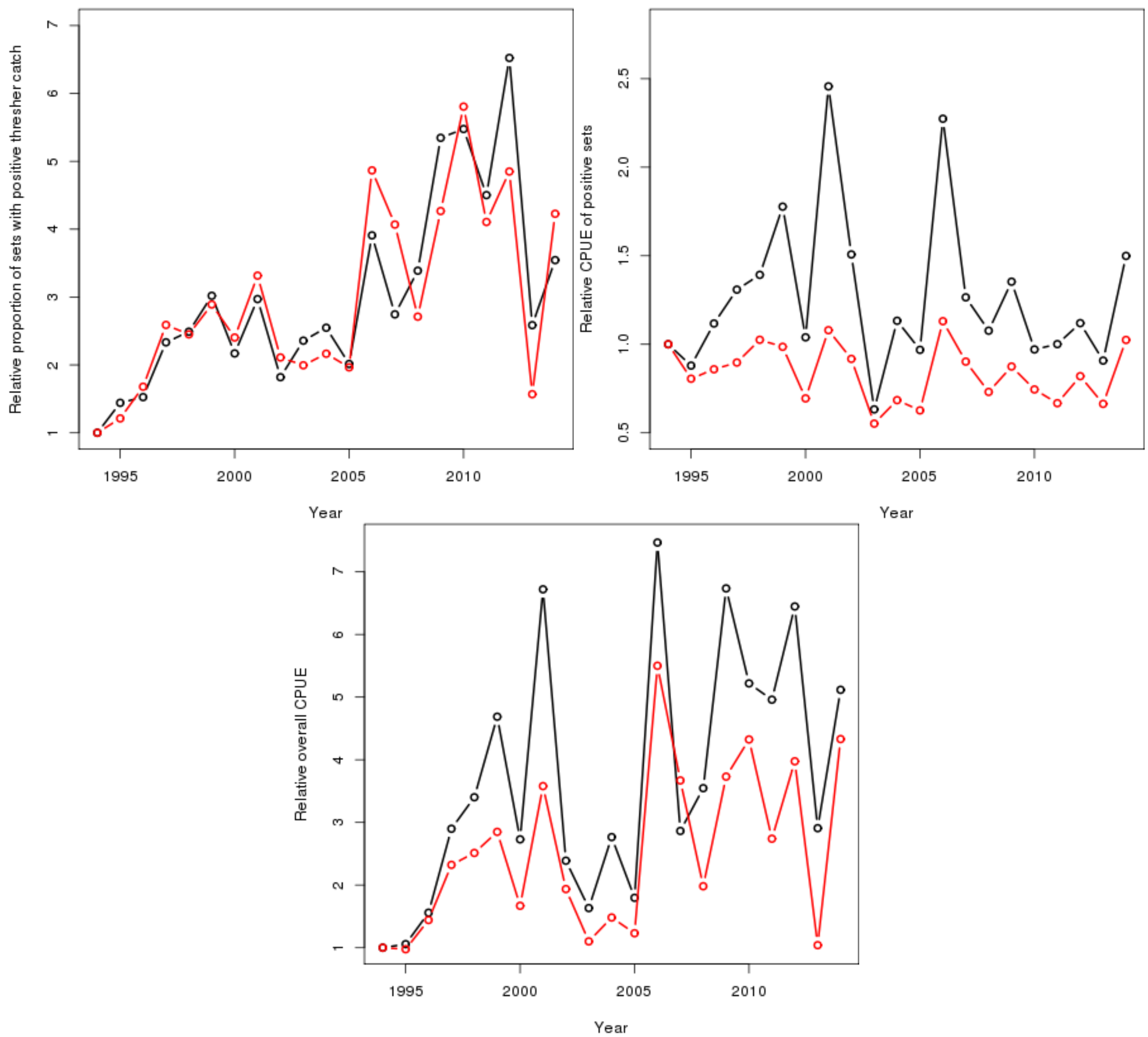
Appendix Figure B.5. Residual plots of the lognormal portion of the delta-lognormal model used to standardize the 1994 – 2014 common thresher shark abundance index for the USSN fishery.



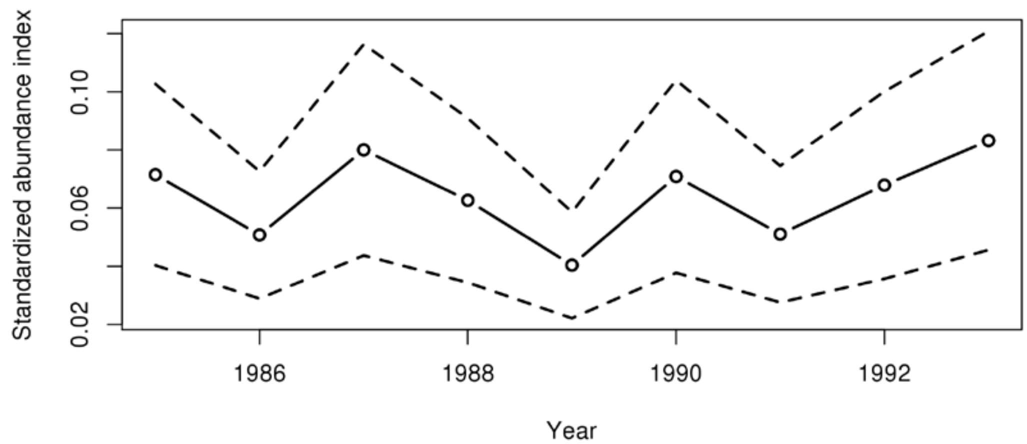
Appendix Figure B.6. Residual plots of the binomial portion of the delta-lognormal model used to standardize the 1994 – 2014 common thresher shark abundance index for the USSN fishery.

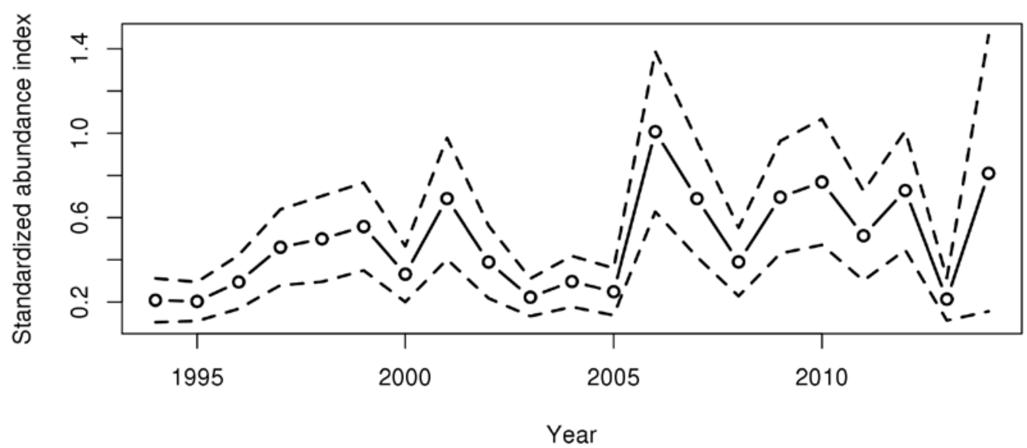


Appendix Figure B.7. Relative proportion of positive sets (upper left), CPUE of positive sets (upper right), and overall CPUE (lower) of nominal (black) and standardized (red) CPUE of the USSN fishery during 1985 – 1993. Indices are plotted relative to the value of the initial year.



Appendix Figure B.8. Relative proportion of positive sets (upper left), CPUE of positive sets (upper right), and overall CPUE (lower) of nominal (black) and standardized (red) CPUE of the USSN fishery during 1994 – 2014. Indices are plotted relative to the value of the initial year.





Appendix Figure B.9. Standardized abundance indices of the USSN fishery during two periods: 1985 – 1993 (upper), and 1994 – 2014 (lower). Dashed lines indicate 95% confidence intervals derived from jackknifing the data set.

APPENDIX C: Abundance index for the USA juvenile thresher shark survey

INTRODUCTION

The Southwest Fisheries Science Center (SWFSC) has conducted an annual juvenile thresher survey in September from 2006 through 2014. This fishery-independent survey was developed after an initial study on the nursery ground of the common thresher shark (Smith 2005). The study indicated that longline gear in nearshore waters would be successful in catching young-of-year and juvenile common thresher sharks.

The basic survey design consisted of 12 area blocks and a minimum of three longline sets were required for each block (Fig. C.1). Each longline set consisted of a one mile long pelagic monofilament longline with 100 hooks. The longline was deployed from a small commercial longline vessel and anchored at each end. The hooks were expected to fish approximately 6-8 m below the surface and were baited with primarily sardines but mackerels were sometimes used when sardines were not available. The longline sets were deployed in areas where bottom depth is <25 fathoms (~45 m). Sharks were tagged and released alive, if possible.

Several operational factors of this survey impacted how the data from this survey was utilized in this assessment. Most importantly, the location and timing of each set was determined by the captain of the vessel, within the constraints set by NOAA scientists. The sets were in effect targeted at thresher sharks and were somewhat similar to commercial longline sets, albeit with standardized fishing gear. In addition, after the initial three sets within a block were completed and there was time available, the captain was free to set again in the same area. Therefore, the first three sets in an area block could have been used as learning sets, and may have provided information on where it was more likely to encounter common thresher sharks during subsequent sets in the same block. Preliminary analysis of the catch-per-unit-effort (CPUE) indicated that sets after the initial three sets in an area had a significant positive effect on encountering non-zero thresher catch.

Another important factor was that soak times of each set were inconsistent and varied substantially (Table C.1). When relatively large numbers of sharks were caught, soak times were sometimes cut to reduce shark mortality and possible hook saturation. Occasionally on some sets in the past, if a shark was observed to be hooked, the shark would be brought aboard and released, and the hook was then rebaited and put back into the water. This practice was considered inappropriate and has since been discontinued.

Other secondary factors likely impacting the CPUE of the survey were Marine Protected Areas (MPAs) and consumption of baits by sea lions. In 2012, several areas within survey blocks became unavailable to the survey due to MPAs being implemented. Preliminary analysis indicated that sets within those areas before they became MPAs had higher CPUEs. Sea lions would also occasionally consume the baits on the longline making the longline less effective in catching fish. If the survey data indicated that baits were consumed by sea lions, the data from the set were discarded before further analysis.

MATERIALS AND METHODS

Data

The abundance index was developed using set-by-set data from 2006 through 2014. A series of criteria was used to identify sets with abnormal fishing operations: 1) sets with important missing data; 2) sets conducted outside of established area blocks; 2) sets with depth >25 fathoms; 3) sets where sea lions were observed to consume baits; 4) sets outside of September; 5) experimental sets with non-standard gear configurations (e.g., one set used only 50 hooks); and 6) sets with soak time of >4 hours. A total of 35 sets with abnormal fishing operations were identified out of 440 sets in the initial dataset. The remaining 405 sets were used to derive the abundance index, with some variability in the number of sets for each year (Table C.1).

The data were divided into strata based on available factors. Twelve areas were defined based on the experimental blocks. Other factors included water depth (5 levels: [0,10), [10,20), [20,30), [30,40), and [40,50] m), bait – percentage of sardine (4 levels: [0,25), [25,50), [50,75), and [75,100] %), first 3 sets (2 levels: 0, 1), and MPA sets (2 levels: 0, 1). We used soak time in hours as the fishing effort of each set because soak times varied substantially from set to set (Table C.1) but the number of hooks used were relatively constant (401 sets used 100 hooks but 4 sets used 104 hooks) for each set.

Models

Delta-lognormal models (Lo et al. 1992) were used to standardize the catch per unit effort (CPUE) to obtain the abundance indices used in the stock assessment because the data set contained a large proportion of sets with zero thresher catch (Fig. C.2). Catch was defined as the sum of all common thresher sharks caught in a single set, and effort was defined as the soak time (hours). A delta-lognormal model assumes that the proportion of sets with positive catch has a binomial error structure and is modeled by a GLM with a logit link function, and the catch rate of sets with positive catch has a lognormal error distribution and is modeled by a lognormal GLM. The standardized index is the product of the back-transformed marginal year effects (Searle 1980) of these two components, with a correction for the bias in the lognormal back transformation. Estimates of variance were obtained by jackknifing the data set, using a modified version of delta_glm_1-7-2 function (E. J. Dick, pers. comm.) in R (function was modified to allow for different factors for the binomial and lognormal functions).

A forward-backward stepwise model selection process, with AIC as the selection criteria, was used to determine the set of factors that explained the catch of common thresher sharks in the survey data. The binomial and lognormal models for each time period were selected independently.

RESULTS AND DISCUSSION

Based on the stepwise model selection process, the final delta-lognormal models were:

2006 – 2014

Binom: $\text{logit}(\pi) \sim \text{year} + \text{area} + \text{first3sets} + \text{offset}[\log(\text{eff})] + \varepsilon$

Lognormal: $\log(\text{catch}) \sim \text{year} + \text{area} + \text{mpasets} + \text{offset}[\log(\text{eff})] + \varepsilon$

where π was the probability of a set having positive common thresher shark catch, and the random error structures of the binomial and lognormal models were assumed to be Binom(n, π) and N(0, σ) respectively. Deviance tables for both time periods are found in Table C.2. No first-order interactions were included in the final model selection process because abundance indices with or without first-order interactions were highly similar.

Model diagnostics indicated adequate performance of the lognormal and binomial models for all three abundance indices (Fig. C.3 – C.4). The lognormal residuals were relatively well represented by a normal distribution. In addition, the mean predicted values of both the lognormal and binomial component models were highly representative of the observed values after aggregation into spatial and temporal bins.

The standardized index from the USA juvenile thresher survey showed a generally increasing trend in recruitment from 2006 through 2011 but a decreasing trend in the last three years (2012 – 2014) (Fig. C.5). However, the apparent trends in the index are highly uncertain because the jackknife procedure resulted in large coefficients of variation (CVs), ranging from 0.43 to 0.55 (Table C.3 and Fig. C.6).

Appendix Table C.1. Catch and effort from the longline juvenile thresher shark survey conducted in nearshore waters of Southern California by NOAA Fisheries' Southwest Fisheries Science Center. Each longline set consists 100 hooks except for 4 sets with 104 hooks.

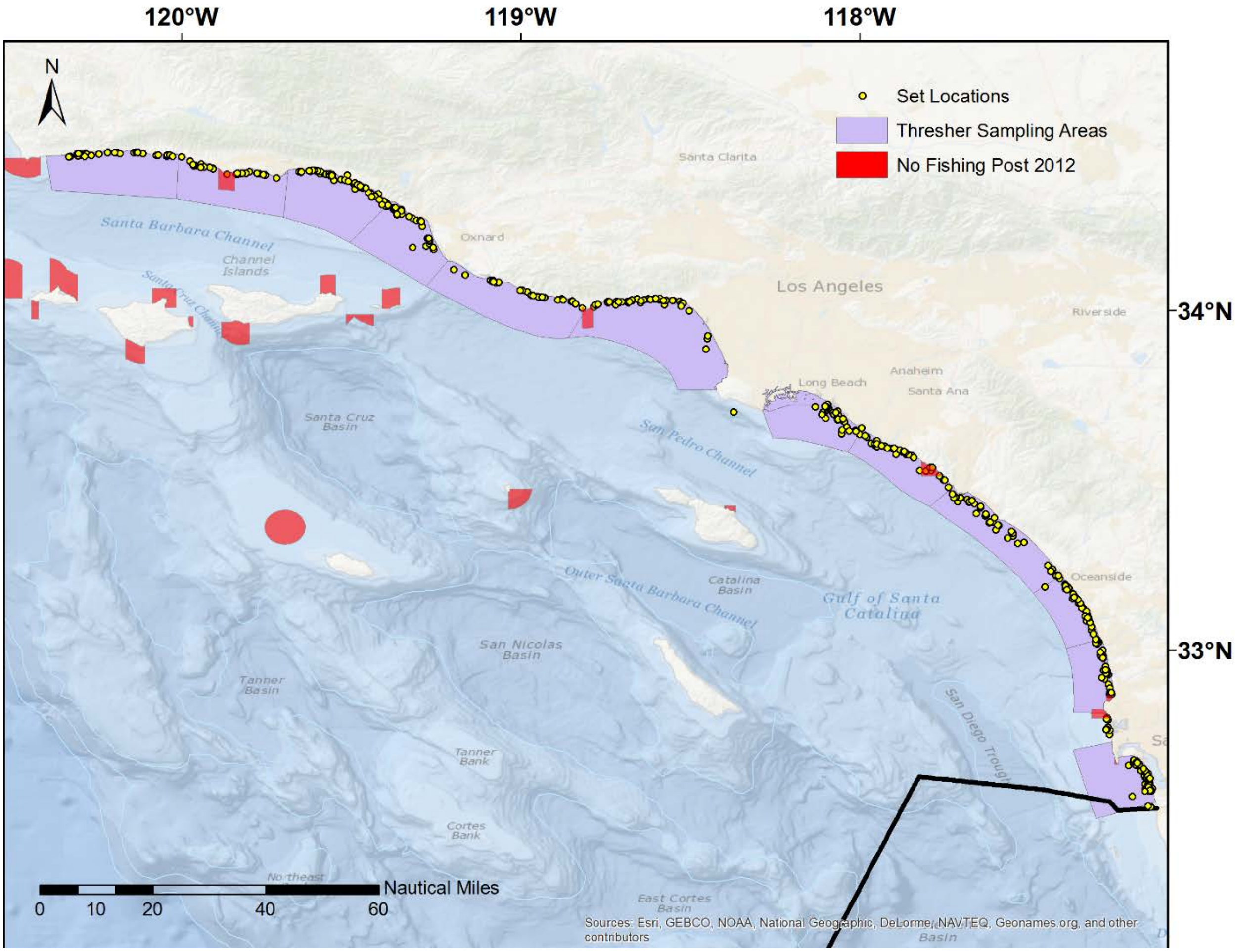
Year	**Number of sets prior to filtering**	**Number of sets after filtering**	**Number of common thresher sharks**	**Soak time (h) Mean ± SD**
2006	50	45	253	2.3 ± 0.5
2007	49	44	113	2.3 ± 0.4
2008	48	41	282	2.2 ± 0.5
2009	50	47	213	2.3 ± 0.4
2010	48	43	263	2.1 ± 0.5
2011	47	46	412	2.1 ± 0.6
2012	50	45	268	2.3 ± 0.4
2013	49	47	285	2.4 ± 0.4
2014	49	47	147	2.2 ± 0.3

Appendix Table C.2. Deviance analysis of explanatory variables in delta-lognormal models for common thresher shark catch rates of USA juvenile thresher survey for 2006 – 2014.

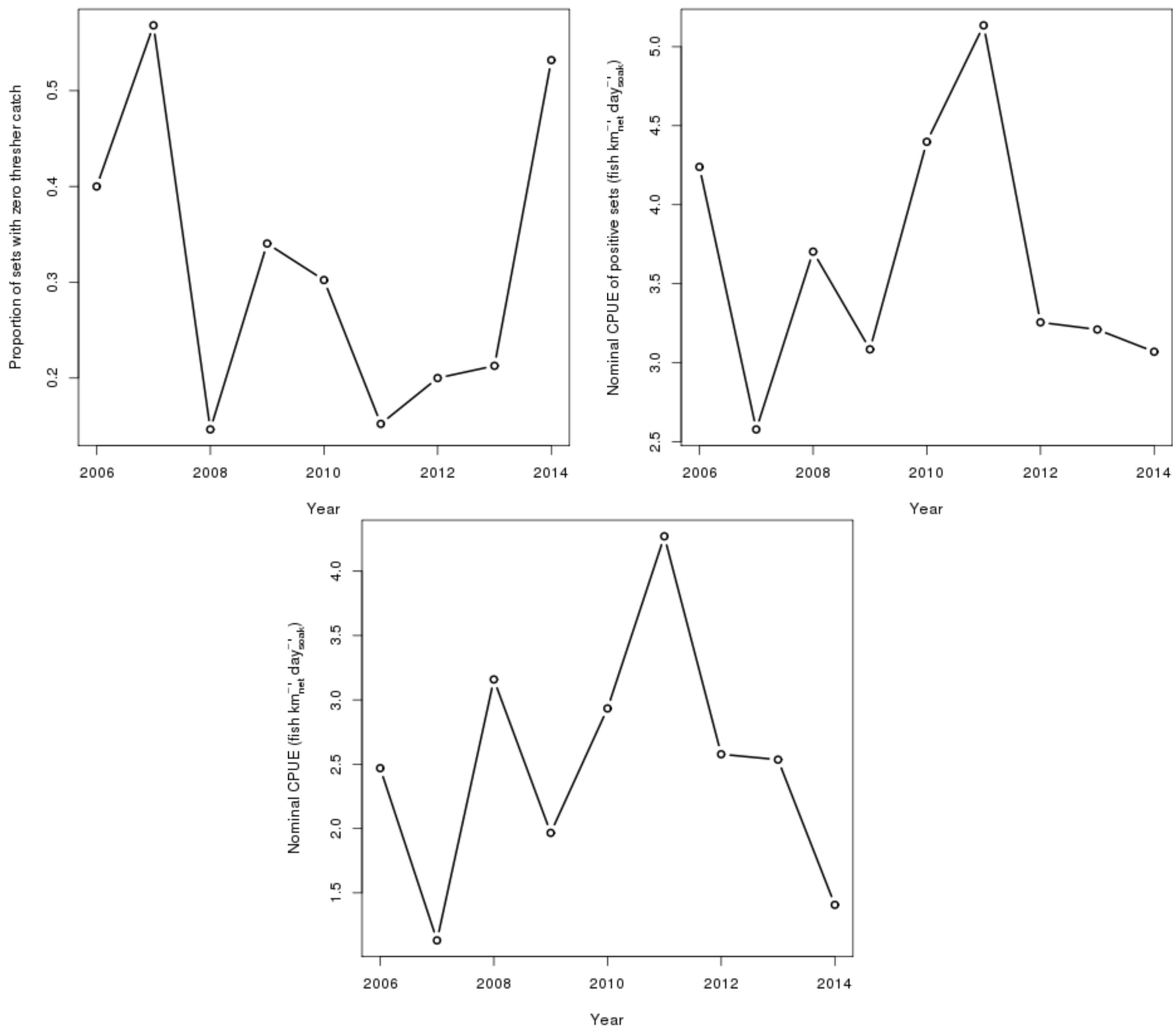
Model factors	**Df**	**Deviance**	**Residual Df**	**Residual Deviance**	**Pr(>Chi)**
Binomial: AIC = 464.0					
Null			404	521.95	
Year	8	43.41	396	478.54	7.35E-07
Area	11	50.11	385	428.43	5.98E-07
First 3 sets in an area block	1	6.45	384	421.99	0.0111
Lognormal: AIC = 841.7					
Null			275	336.08	
Year	8	13.14	267	322.93	0.1737
Area	11	25.76	256	297.17	0.0202
Set in MPA	1	6.37	255	290.80	0.0181

Table C.3. Estimated relative abundance index values, standard errors (SEs), and coefficients of variation (CVs) for the USA juvenile thresher survey. The SEs and CVs were estimated with a jackknife procedure.

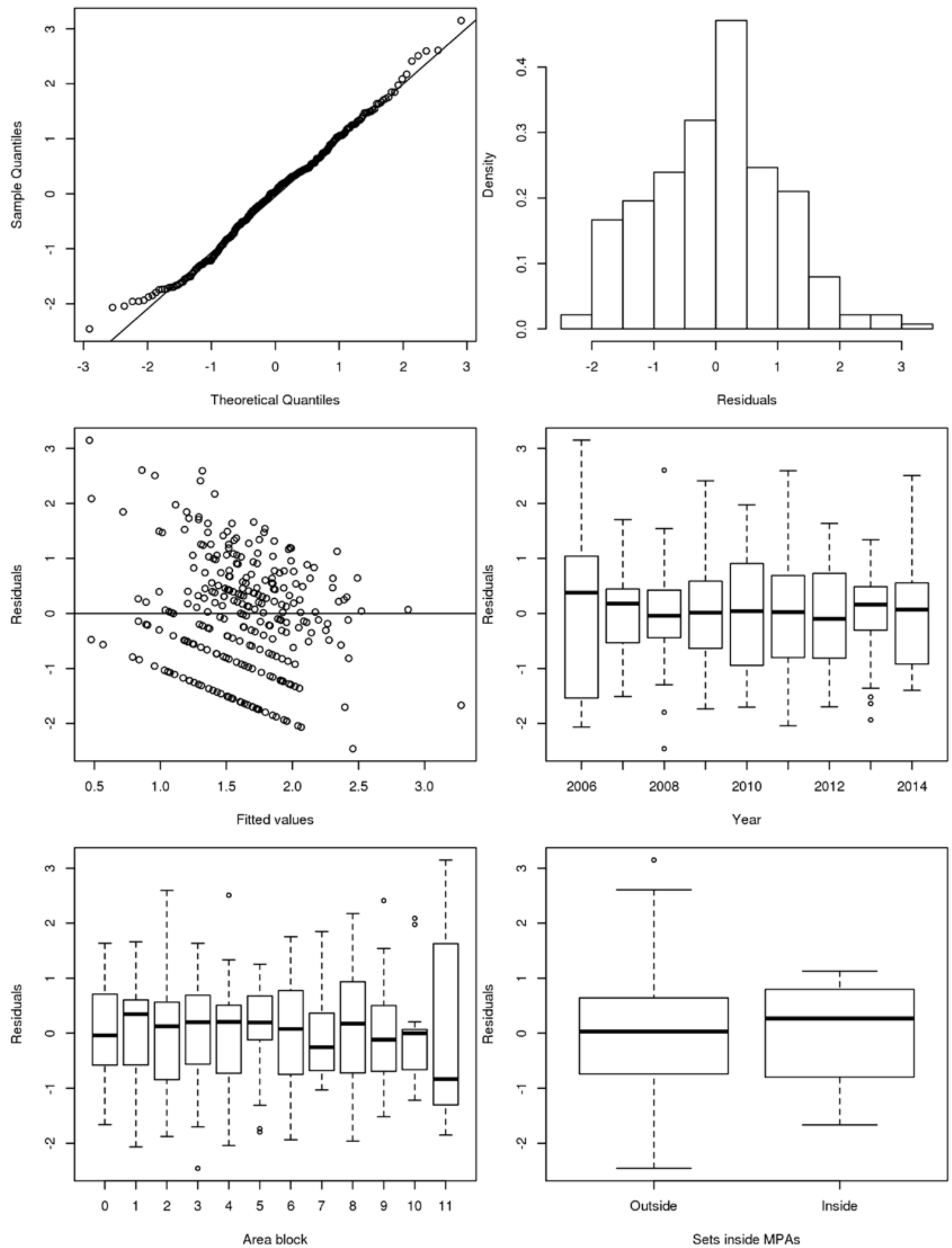
Year	**Index**	**SE**	**CV**
2006	3.20419	1.75810	0.54869
2007	1.70947	0.87744	0.51328
2008	7.64873	3.57938	0.46797
2009	3.04584	1.43589	0.47143
2010	5.43268	2.33678	0.43013
2011	8.82981	4.38673	0.49681
2012	4.87355	2.22676	0.45691
2013	5.18471	2.36088	0.45535
2014	1.73476	0.90736	0.52305



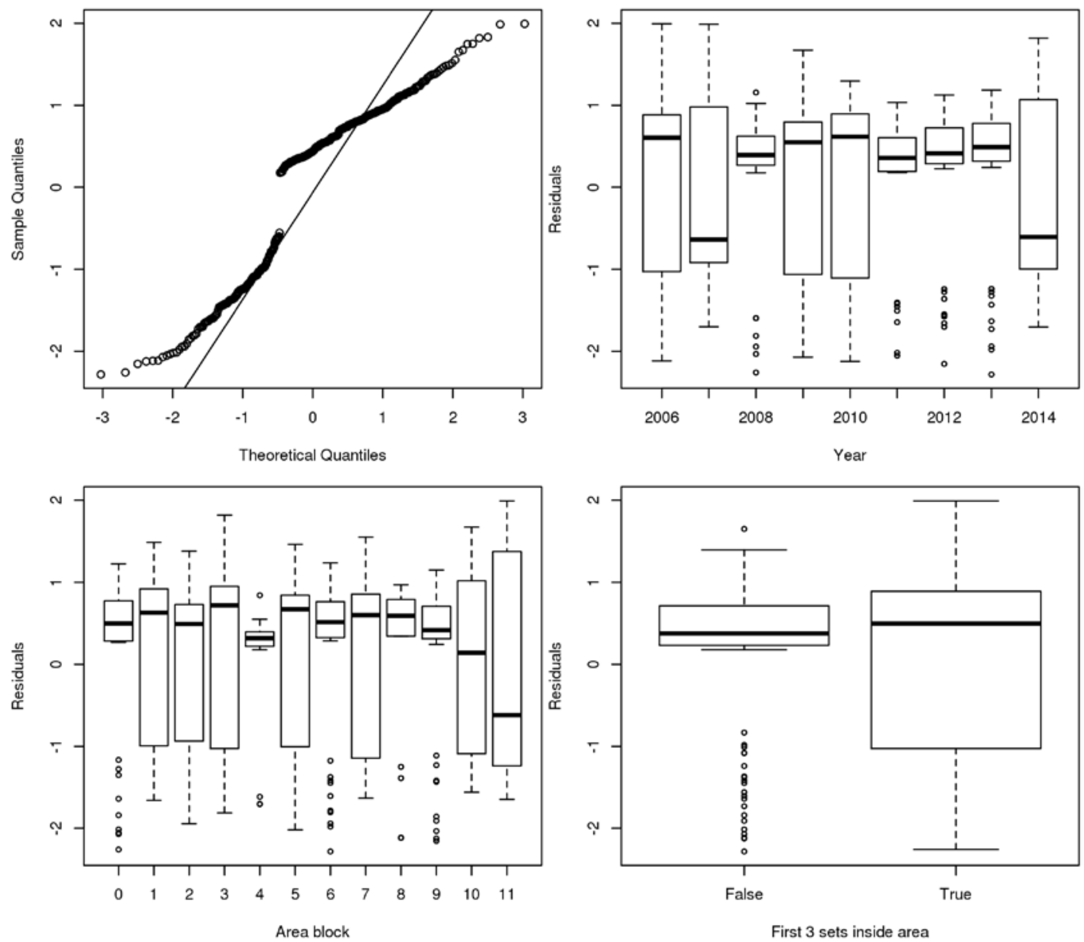
Appendix Figure C.1. Locations of 440 sets and 12 sampling areas of the U.S. juvenile thresher shark survey from 2006 through 2014. Areas where fishing was prohibited after 2012 (i.e., MPAs) are shown in red.



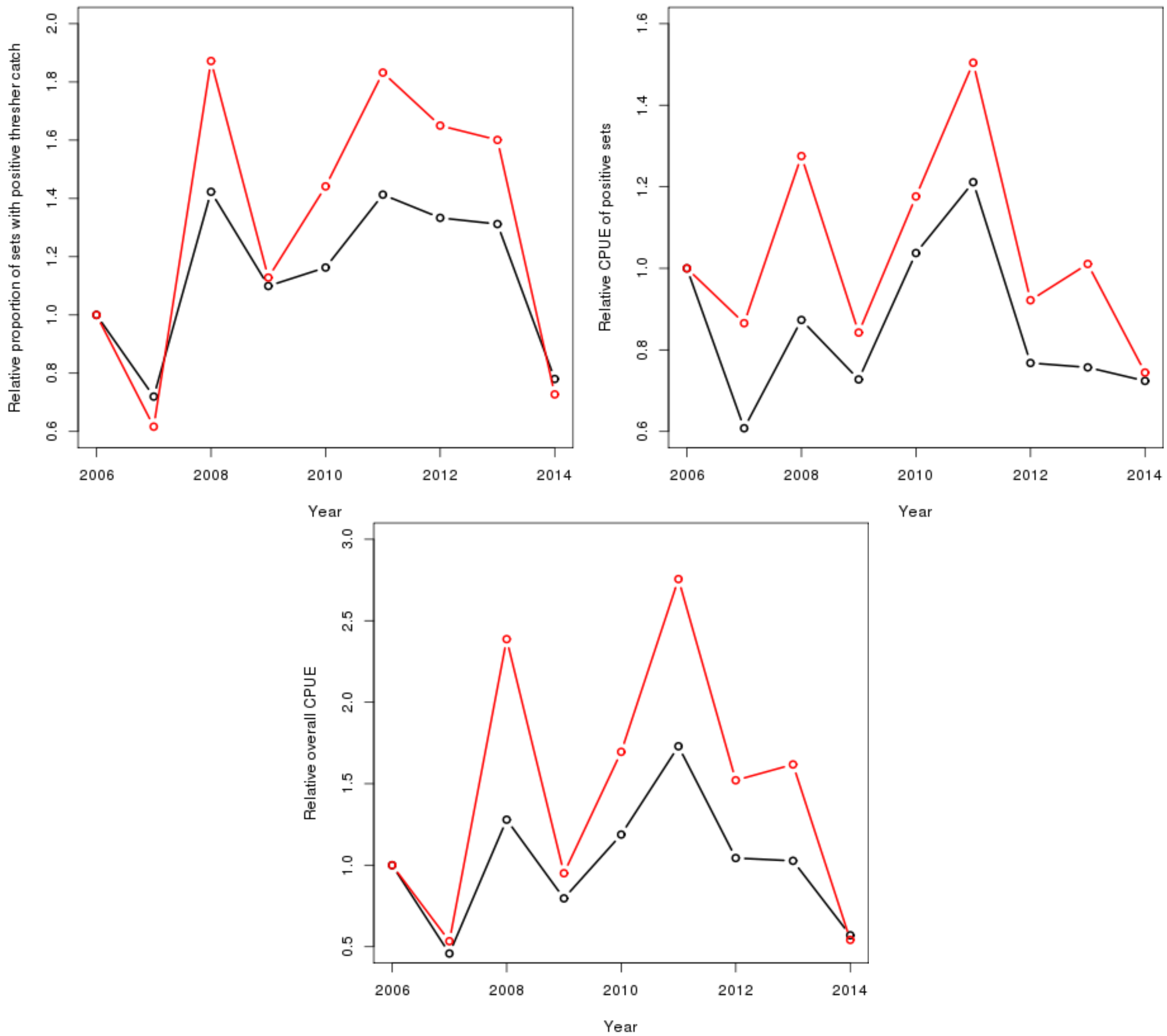
Appendix Figure C.2. Proportion of sets with zero thresher shark catch (upper), nominal catch-per-unit-effort (CPUE) of sets with positive thresher catch (middle), and overall nominal CPUE (lower) for common thresher sharks caught by the USA juvenile thresher survey.



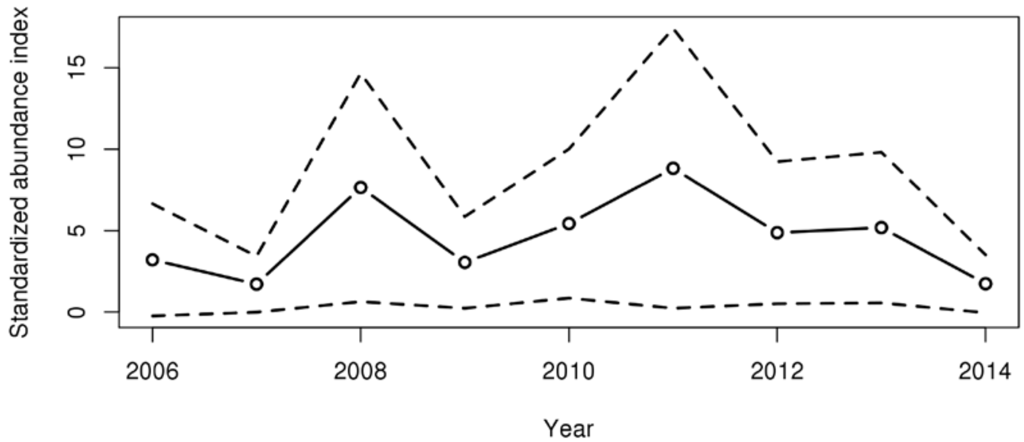
Appendix Figure C.3. Residual plots of the lognormal portion of the delta-lognormal model used to standardize the 2006 – 2014 common thresher shark abundance index for the USA juvenile thresher survey.



Appendix Figure C.4. Residual plots of the binomial portion of the delta-lognormal model used to standardize the 2006 – 2014 common thresher shark abundance index for the USA juvenile thresher survey.



Appendix Figure C.5. Relative proportion of positive sets (upper left), CPUE of positive sets (upper right), and overall CPUE (lower) of nominal (black) and standardized (red) CPUE of the USA juvenile thresher survey. Indices are plotted relative to the value of the initial year.



Appendix Figure C.6. Standardized abundance indices of the USA juvenile thresher survey. Dashed lines indicate 95% confidence intervals derived from jackknifing the data set.

APPENDIX D: Common thresher shark assessment model files

Starter file

```
#V3.24U
#C 2015 thresher shark assessment
2015_THR_dat.txt
2015_THR_ctl.txt
0 # 0=use init values in control file; 1=use ss3.par
1 # run display detail (0,1,2)
1 # detailed age-structured reports in REPORT.SSO (0,1)
0 # write detailed info from first call to echoinput.sso (0,1)
0 # write parm values to ParmTrace.sso (0=no,1=good,active; 2=good,all; 3=every_iter,all_parms; 4=every,active)
1 # write to cumreport.sso (0=no,1=like&timeseries; 2=add survey fits)
0 # Include prior_like for non-estimated parameters (0,1)
1 # Use Soft Boundaries to aid convergence (0,1) (recommended)
1 # Number of datafiles to produce: 1st is input, 2nd is estimates, 3rd and higher are bootstrap
10 # Turn off estimation for parameters entering after this phase
10 # MCeval burn interval
2 # MCeval thin interval
0 # jitter initial parm value by this fraction
1967 # min yr for sdreport outputs (-1 for styr)
2014 # max yr for sdreport outputs (-1 for endyr; -2 for endyr+Nforecastyrs
0 # N individual STD years
#vector of year values

0.0001 # final convergence criteria (e.g. 1.0e-04)
0 # retrospective year relative to end year (e.g. -4)
1 # min age for calc of summary biomass
1 # Depletion basis:  denom is: 0=skip; 1=rel X*B0; 2=rel X*Bmsy; 3=rel X*B_styr
1 # Fraction (X) for Depletion denominator (e.g. 0.4)
4 # SPR_report_basis:  0=skip; 1=(1-SPR)/(1-SPR_tgt); 2=(1-SPR)/(1-SPR_MSY); 3=(1-SPR)/(1-SPR_Btarget); 4=rawSPR
1 # F_report_units: 0=skip; 1=exploitation(Bio); 2=exploitation(Num); 3=sum(Frates); 4=true F for range of ages
#COND 10 15 #_min and max age over which average F will be calculated with F_reporting=4
2 # F_report_basis: 0=raw; 1=F/Fspr; 2=F/Fmsy ; 3=F/Fbtgt
999 # check value for end of file
```

Forecast file

```
#V3.24U
#C 2015 thresher shark assessment
# for all year entries except rebuilder; enter either: actual year, -999 for styr, 0 for endyr, neg number for rel. endyr
1 # Benchmarks: 0=skip; 1=calc F_spr,F_btgt,F_msy
2 # MSY: 1= set to F(SPR); 2=calc F(MSY); 3=set to F(Btgt); 4=set to F(endyr)
0.5 # SPR target (e.g. 0.40)
0.5 # Biomass target (e.g. 0.40)
#_Bmark_years: beg_bio, end_bio, beg_selex, end_selex, beg_relF, end_relF (enter actual year, or values of 0 or -integer to be rel. endyr)
 -4 0 -4 0 -4 0
#  2010 2014 2010 2014 2010 2014 # after processing
1 #Bmark_relF_Basis: 1 = use year range; 2 = set relF same as forecast below
#
0 # Forecast: 0=none; 1=F(SPR); 2=F(MSY) 3=F(Btgt); 4=Ave F (uses first-last relF yrs); 5=input annual F scalar
0 # N forecast years
0 # F scalar (only used for Do_Forecast==5)
#_Fcast_years:  beg_selex, end_selex, beg_relF, end_relF  (enter actual year, or values of 0 or -integer to be rel. endyr)
 2010 2014 2010 2014
#  1180631114 1667592815 7631713 1936290657 # after processing
0 # Control rule method (1=catch=f(SSB) west coast; 2=F=f(SSB) )
0 # Control rule Biomass level for constant F (as frac of Bzero, e.g. 0.40); (Must be > the no F level below)
0 # Control rule Biomass level for no F (as frac of Bzero, e.g. 0.10)
0.75 # Control rule target as fraction of Flimit (e.g. 0.75)
3 #_N forecast loops (1=OFL only; 2=ABC; 3=get F from forecast ABC catch with allocations applied)
3 #_First forecast loop with stochastic recruitment
0 #_Forecast loop control #3 (reserved for future bells&whistles)
0 #_Forecast loop control #4 (reserved for future bells&whistles)
0 #_Forecast loop control #5 (reserved for future bells&whistles)
0  #FirstYear for caps and allocations (should be after years with fixed inputs)
0 # stddev of log(realized catch/target catch) in forecast (set value>0.0 to cause active impl_error)
0 # Do West Coast gfish rebuilder output (0/1)
0 # Rebuilder:  first year catch could have been set to zero (Ydecl)(-1 to set to 1999)
0 # Rebuilder:  year for current age structure (Yinit) (-1 to set to endyear+1)
1 # fleet relative F:  1=use first-last alloc year; 2=read seas(row) x fleet(col) below
# Note that fleet allocation is used directly as average F if Do_Forecast=4
0 # basis for fcast catch tuning and for fcast catch caps and allocation  (2=deadbio; 3=retainbio; 5=deadnum; 6=retainnum)
# Conditional input if relative F choice = 2
# Fleet relative F:  rows are seasons, columns are fleets
#_Fleet:  F1_US_DGN_9114 F2_US_DGN_8690 F3_US_DGN_6985 F4_US_SN_9114 F5_US_SN_6990 F6_US_OTH F7_US_REC
F8_MX_DGN F9_MX_LL F10_MX_ART
#  0 0 0 0 0 0 0 0 0 0
#  0 0 0 0 0 0 0 0 0 0
#  0 0 0 0 0 0 0 0 0 0
#  0 0 0 0 0 0 0 0 0 0
# max totalcatch by fleet (-1 to have no max) must enter value for each fleet

# max totalcatch by area (-1 to have no max); must enter value for each fleet

# fleet assignment to allocation group (enter group ID# for each fleet, 0 for not included in an alloc group)

#_Conditional on >1 allocation group
# allocation fraction for each of: 0 allocation groups
# no allocation groups
0 # Number of forecast catch levels to input (else calc catch from forecast F)
2 # code means to read fleet/time specific basis (2=dead catch; 3=retained catch; 99=F)  as below (units are from fleetunits; note new codes in
SSV3.20)
# Input fixed catch values
#Year Seas Fleet Catch(or_F) Basis
#
999 # verify end of input
```

Data file

```
#V3.24U
#_SS-V3.24U-fast;_08/29/2014;_Stock_Synthesis_by_Richard_Methot_(NOAA)_using_ADMB_11.2_Linux64_compiled_on_RHEL6.6
#_Start_time: Mon Aug 31 11:55:19 2015
#_Number_of_datafiles: 1
#C 2015 thresher shark assessment
#C FleetID   FleetID2   Description                       Shortname    Comments
#C 1         F1         US_DGN_fishery                    USDGN        Incl_US_Misc_catch
#C 2         F2         US_DGN_fishery_Seas2              USDGNs2      Incl_US_Misc_catch
#C 3         F3         US_SN_fishery                     USSN
#C 4         F4         US_Rec_Fishery                    USREC
#C 5         F5         US_Rec_Fishery_Seas2              USRECs2
#C 6         F6         MX_DGN_LL_Fishery                 MXDGNLL
#C 7         F7         MX_DGN_LL_Fishery_Seas2           MXDGNLLs2
#C 8         F8         MX_Artisanal_Fishery              MXART
#C 9         S1         US_DGN_Index_1_(1982-1984)        USDGN8284
#C 10        S2         US_DGN_Index_2_(1992-2000)        USDGN9200
#C 11        S3         US_DGN_Index_3_(2001-2013)        USDGN0113
#C 12        S4         US_SN_Index_1_(1985-1993)         USSN8593
#C 13        S5         US_SN_Index_2_(1994-2014)         USSN9414
#C 14        S6         US_Juvy_Thr_Survey_(2006-2014)    USJUV0614
#_observed data:
1969 #_styr
2014 #_endyr
4 #_nseas
 3 3 3 3 #_months/season
2 #_spawn_seas
8 #_Nfleet
6 #_Nsurveys
1 #_N_areas
F1%F2%F3%F4%F5%F6%F7%F8%S1%S2%S3%S4%S5%S6
 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 #_surveytiming_in_season
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 #_area_assignments_for_each_fishery_and_survey
 1 1 1 2 2 1 1 1 #_units of catch:  1=bio; 2=num
 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 #_se of log(catch) only used for init_eq_catch and for Fmethod 2 and 3; use -1 for discard only fleets
2 #_Ngenders
25 #_Nages
 94.08 0 0 1.16 0 0 0 23.26 #_init_equil_catch_for_each_fishery
184 #_N_lines_of_catch_to_read
#_catch_biomass(mtons):_columns_are_fisheries,year,season
 13.575 0 0.145 0.147 0 0 0 4.026 1969 1
 0 17.435 0.698 0 0.564 0 0 4.745 1969 2
 34.853 0 0.638 0.14 0 0 0 6.586 1969 3
 35.953 0 0.341 0.315 0 0 0 5.554 1969 4
 11.463 0 0.277 0.151 0 0 0 4.026 1970 1
 0 32.273 1.296 0 0.56 0 0 4.745 1970 2
 43.62 0 0.702 0.135 0 0 0 6.586 1970 3
 31.905 0 0.558 0.315 0 0 0 5.554 1970 4
 0 0 0 0.147 0 0 0 4.026 1971 1
 0 39.773 1.723 0 0.56 0 0 4.745 1971 2
 21.396 0 0.681 0.134 0 0 0 6.586 1971 3
 0 0 0 0.315 0 0 0 5.554 1971 4
 21.698 0 0.222 0.147 0 0 0 4.026 1972 1
 0 20.423 1.563 0 0.565 0 0 4.745 1972 2
 49.547 0 0.674 0.134 0 0 0 6.586 1972 3
 28.075 0 0 0.315 0 0 0 5.554 1972 4
 0 0 0 0.148 0 0 0 4.026 1973 1
 0 70.778 0.844 0 0.561 0 0 4.745 1973 2
 42.041 0 0.342 0.136 0 0 0 6.586 1973 3
 0 0 0 0.316 0 0 0 5.554 1973 4
 35.527 0 0.425 0.149 0 0 0 4.026 1974 1
 0 23.371 0.885 0 0.567 0 0 4.745 1974 2
 63.537 0 0.501 0.143 0 0 0 6.586 1974 3
 21.803 0 0.666 0.319 0 0 0 5.554 1974 4
 36.936 0 0.416 0.147 0 0 0 4.026 1975 1
 0 97.193 2.725 0 0.565 0 0 4.745 1975 2
 76.647 0 0.891 0.136 0 0 0 6.586 1975 3
 30.333 0 1.11 0.316 0 0 0 5.554 1975 4
 60.629 0 0.587 0.148 0 0 0 5.766 1976 1
```

0 133.512 3.814 0 0.576 0 0 6.795 1976 2
84.183 0 1.025 0.14 0 0 0 9.433 1976 3
119.07 0 2.267 0.316 0 0 0 7.423 1976 4
75.888 0 0.897 0.148 0 0 0 3.217 1977 1
0 166.995 5.777 0 0.56 0 0 3.792 1977 2
90.792 0 0.849 0.138 0 0 0 5.263 1977 3
79.385 0 1.409 0.316 0 0 0 4.572 1977 4
30.784 0 0.917 0.149 0 0 0 3.094 1978 1
0 254.099 20.189 0 0.564 0 0 3.647 1978 2
221.231 0 7.829 0.14 0 0 0 5.063 1978 3
70.825 0 2.985 0.315 0 0 0 4.667 1978 4
80.767 0 3.167 0.147 0 0 0 3.793 1979 1
0 380.274 28.828 0 0.56 0 0 4.469 1979 2
412.994 0 13.988 0.134 0 0 0 6.204 1979 3
251.458 0 9.542 0.315 0 0 0 6.631 1979 4
210.589 0 2.102 0.409 0 0 0 7.409 1980 1
0 486.396 12.057 0 0.004 0 0 8.732 1980 2
1057.19 0 14.466 0.006 0 0 0 12.12 1980 3
371.022 0 7.485 0.001 0 0 0 11.472 1980 4
247.716 0 6.842 0.002 0 0 0 9.988 1981 1
0 747.883 35.041 0 0.001 0 0 11.772 1981 2
495.486 0 21.525 0.002 0 0 0 16.341 1981 3
98.94 0 10.684 0.112 0 0 0 16.389 1981 4
381.602 0 17.904 0.111 0 0 0 16.261 1982 1
0 846.657 93.796 0 0.21 0 0 19.164 1982 2
449.797 0 23.516 0.195 0 0 0 26.604 1982 3
131.6 0 8.184 1.615 0 0 0 22.703 1982 4
1.37 0 0.795 0.201 0 0 0 14.428 1983 1
0 835.471 44.009 0 3.002 0 0 17.004 1983 2
307.478 0 15.879 0.086 0 0 0 23.605 1983 3
129.295 0 6.574 0.199 0 0 0 19.044 1983 4
23.275 0 2.405 0.174 0 0 0 9.473 1984 1
0 754.332 94.897 0 0.003 0 0 11.164 1984 2
267.822 0 3.868 0.437 0 0 0 15.497 1984 3
156.155 0 1.089 0 0 0.182 0 11.438 1984 4
4.121 0 0.161 0.001 0 3.042 0 2.997 1985 1
0 890.693 64.837 0 0.194 0 2.73 3.533 1985 2
205.963 0 0.827 0.208 0 2.366 0 4.904 1985 3
31.763 0 0.116 0.002 0 1.202 0 5.207 1985 4
3.087 0 0.44 1.361 0 13.145 0 5.755 1986 1
0 325.919 7.126 0 0.007 0 11.797 6.783 1986 2
516.465 0 0.916 0.004 0 10.224 0 9.415 1986 3
141.399 0 0.297 0 0 4.473 0 8.772 1986 4
3.464 0 0.326 0.002 0 44.713 0 7.341 1987 1
0 285.021 14.366 0 4.055 0 40.127 8.651 1987 2
183.88 0 0.531 0.788 0 34.777 0 12.009 1987 3
115.679 0 0.187 0.001 0 9.251 0 10.94 1987 4
7.551 0 0.339 0 0 52.416 0 8.605 1988 1
0 134.527 2.521 0 0.877 0 47.04 10.141 1988 2
252.105 0 0.756 0.009 0 40.768 0 14.078 1988 3
172.918 0 0.111 0 0 9.318 0 10.79 1988 4
4.765 0 0.54 0.001 0 35.93 0 3.932 1989 1
0 114.397 1.857 0 0.015 0 32.245 4.635 1989 2
93.76 0 0.224 0.801 0 27.946 0 6.432 1989 3
236.774 0 0.428 0.005 0 10.218 0 6.476 1989 4
4.168 0 0.366 0.007 0 88.672 0 6.469 1990 1
0 104.646 1.725 0 0.014 0 79.577 7.625 1990 2
150.221 0 1.696 0.023 0 68.967 0 10.585 1990 3
183.285 0 0.143 0 0 16.484 0 8.265 1990 4
2.083 0 0.349 0 0 72.833 0 3.416 1991 1
0 147.652 2.143 0 0 0 65.364 4.026 1991 2
224.521 0 0.226 0 0 56.648 0 5.589 1991 3
83.363 0 0.037 0 0 18.01 0 5.853 1991 4
1.657 0 0.256 0 0 134.556 0 6.311 1992 1
0 154.858 1.74 0 0 0 120.756 7.439 1992 2
98.023 0 0.415 0 0 104.655 0 10.324 1992 3
39.229 0 0.032 0 0 26.931 0 8.251 1992 4
5.601 0 0.834 0 0 142.569 0 3.901 1993 1
0 38.035 0.811 0 0.869 0 127.946 4.597 1993 2
126.071 0 0.227 1.371 0 110.887 0 6.382 1993 3

105.898 0 1.123 0.486 0 27.017 0 5.439 1993 4
21.083 0 4.555 0.225 0 125.698 0 3.44 1994 1
0 63.517 2.181 0 1.72 0 112.806 4.053 1994 2
121.692 0 1.579 1.655 0 97.765 0 5.626 1994 3
137.772 0 1.003 0 0 22.388 0 4.58 1994 4
3.865 0 1.162 1.744 0 86.897 0 2.377 1995 1
0 56.175 2.758 0 0.455 0 77.984 2.802 1995 2
91.982 0 1.606 0.455 0 67.587 0 3.889 1995 3
114.492 0 4.819 0 0 19.383 0 3.755 1995 4
1.444 0 1.721 0 0 125.359 0 3.43 1996 1
0 84.522 4.7 0 0.627 0 112.502 4.042 1996 2
158.23 0 2.497 0.076 0 97.502 0 5.611 1996 3
118.696 0 1.734 0 0 25.551 0 5.054 1996 4
10.406 0 1.142 0 0 140.54 0 3.845 1997 1
0 55.041 6.104 0 0.126 0 126.126 4.532 1997 2
124.866 0 6.244 0.126 0 109.31 0 6.291 1997 3
65.541 0 1.335 0.209 0 29.468 0 5.946 1997 4
1.266 0 1.028 0 0 166.758 0 5.16 1998 1
0 84.785 5.933 0 0.464 0 148.785 6.081 1998 2
148.729 0 3.124 0.128 0 129.037 0 8.441 1998 3
121.263 0 3.12 0.509 0 29.444 0 6.779 1998 4
1.052 0 0.501 0.366 0 92.499 0 3.293 1999 1
0 110.796 12.93 0 0.258 0 81.904 3.882 1999 2
109.953 0 3.544 0.414 0 71.099 0 5.388 1999 3
83.162 0 2.583 0 0 21.704 0 5.561 1999 4
1.643 0 1.507 0.702 0 114.586 0 5.838 2000 1
0 106.118 21.749 0 0.819 0 98.902 6.881 2000 2
71.523 0 3.369 0.819 0 86.124 0 9.55 2000 3
101.473 0 4.103 0 0 27.043 0 8.655 2000 4
2.632 0 3.214 0 0 103.206 0 6.702 2001 1
0 99.66 14.37 0 0.629 0 86.978 7.9 2001 2
125.405 0 3.32 1.574 0 75.967 0 10.966 2001 3
111.216 0 6.902 0 0 26.685 0 9.525 2001 4
12.887 0 1.641 0 0 99.354 0 6.453 2002 1
0 88.237 18.114 0 0.979 0 83.733 7.605 2002 2
115.807 0 1.336 0.665 0 73.134 0 10.557 2002 3
137.652 0 1.444 0 0 25.444 0 9.102 2002 4
11.418 0 8.666 0.167 0 92.483 0 6.006 2003 1
0 72.965 5.357 0 1.722 0 77.941 7.079 2003 2
49.835 0 0.79 0.318 0 68.076 0 9.827 2003 3
73.675 0 1.027 0 0 28.219 0 9.737 2003 4
1.293 0 1.661 0 0 145.006 0 9.418 2004 1
0 23.924 12.382 0 0.285 0 122.206 11.1 2004 2
22.867 0 1.434 0.033 0 106.736 0 15.407 2004 3
39.687 0 1.177 4.202 0 33.746 0 12.338 2004 4
2.273 0 2.77 0.027 0 90.904 0 5.904 2005 1
0 29.24 4.56 0 0.124 0 76.609 6.958 2005 2
36.926 0 1.493 0.142 0 66.912 0 9.659 2005 3
116.74 0 0.346 0.014 0 24.032 0 8.537 2005 4
3.872 0 1.01 0.032 0 94.366 0 6.128 2006 1
0 31.372 12.786 0 0.776 0 79.53 7.224 2006 2
55.864 0 1.511 0.135 0 69.462 0 10.026 2006 3
50.217 0 3.056 0 0 25.418 0 8.993 2006 4
2.909 0 2.396 0.009 0 104.078 0 6.76 2007 1
0 24.998 5.015 0 0.627 0 87.714 7.967 2007 2
63.907 0 1.632 0.862 0 76.611 0 11.059 2007 3
98.202 0 0.618 0.036 0 27.83 0 10.084 2007 4
5.992 0 1.135 0.032 0 105.688 0 7.957 2008 1
0 19.665 5.243 0 0.542 0 87.479 9.378 2008 2
65.947 0 2.669 0.512 0 76.583 0 13.018 2008 3
45.951 0 3.818 0.125 0 26.307 0 11.846 2008 4
6.775 0 2.525 0.022 0 25.146 0 9.289 2009 1
0 27.911 5.345 0 0.41 0 10.055 10.948 2009 2
17.242 0 2.504 0.714 0 10.016 0 15.197 2009 3
34.374 0 2.452 0.786 0 19.269 0 13.024 2009 4
7.694 0 5.813 0.046 0 22.756 0 8.406 2010 1
0 22.769 7.47 0 0.776 0 9.099 9.908 2010 2
14.645 0 1.55 0.295 0 9.063 0 13.753 2010 3
32.599 0 1.64 0.076 0 17.016 0 11.547 2010 4
1.229 0 1.192 1.301 0 18.641 0 6.887 2011 1

0 4.939 5.006 0 0.747 0 7.454 8.117 2011 2
7.024 0 1.938 0.342 0 7.425 0 11.266 2011 3
74.068 0 1.377 0.01 0 15.288 0 10.223 2011 4
3.333 0 0.713 0.046 0 21.526 0 7.952 2012 1
0 11.221 2.275 0 0.068 0 8.607 9.372 2012 2
10.191 0 2.807 0.243 0 8.574 0 13.01 2012 3
35.444 0 1.584 0.008 0 17.207 0 11.553 2012 4
1.219 0 0.216 0 0 22.779 0 8.415 2013 1
0 8.529 1.657 0 0.634 0 9.108 9.918 2013 2
4.182 0 0.759 0.147 0 9.073 0 13.767 2013 3
37.382 0 0.55 0.023 0 13.012 0 9.282 2013 4
0.393 0 0.807 0.002 0 20.982 0 7.751 2014 1
0 19.218 3.617 0 0.297 0 8.39 9.136 2014 2
3.094 0 0.529 0.195 0 8.357 0 12.681 2014 3
9.411 0 0.412 0 0 15.169 0 10.353 2014 4

#
64 #_N_cpue_and_surveyabundance_observations
#_Units: 0=numbers; 1=biomass; 2=F
#_Errtype: -1=normal; 0=lognormal; >0=T
#_Fleet Units Errtype
1 0 0 # F1
2 0 0 # F2
3 0 0 # F3
4 0 0 # F4
5 0 0 # F5
6 0 0 # F6
7 0 0 # F7
8 0 0 # F8
9 0 0 # S1
10 0 0 # S2
11 0 0 # S3
12 0 0 # S4
13 0 0 # S5
14 0 0 # S6
#_year seas index obs err
1982 3 9 0.0122918 0.280355 # S1
1983 3 9 0.00920862 0.278143 # S1
1984 3 9 0.00763147 0.27842 # S1
1992 3 10 0.000466618 0.11681 # S2
1993 3 10 0.000655651 0.112893 # S2
1994 3 10 0.00107238 0.112887 # S2
1995 3 10 0.000760164 0.127392 # S2
1996 3 10 0.000985173 0.12568 # S2
1997 3 10 0.00111957 0.119943 # S2
1998 3 10 0.00213771 0.120471 # S2
1999 3 10 0.00126356 0.129961 # S2
2000 3 10 0.00190646 0.148804 # S2
2001 4 11 0.0126904 0.197016 # S3
2002 4 11 0.0063087 0.202422 # S3
2003 4 11 0.00574843 0.211916 # S3
2004 4 11 0.00517914 0.21691 # S3
2005 4 11 0.0182973 0.20352 # S3
2006 4 11 0.00686545 0.1991 # S3
2007 4 11 0.0228914 0.196973 # S3
2008 4 11 0.00684689 0.220957 # S3
2009 4 11 0.00390685 0.225036 # S3
2010 4 11 0.0174454 0.231113 # S3
2011 4 11 0.0114837 0.230211 # S3
2012 4 11 0.00711149 0.22832 # S3
2013 4 11 0.0124422 0.19884 # S3
1985 2 12 0.071494 0.22246 # S4
1986 2 12 0.0507598 0.21999 # S4
1987 2 12 0.0799821 0.23149 # S4
1988 2 12 0.0626452 0.23024 # S4
1989 2 12 0.0403903 0.23055 # S4
1990 2 12 0.070865 0.23839 # S4
1991 2 12 0.0510342 0.23477 # S4
1992 2 12 0.0678798 0.24198 # S4
1993 2 12 0.0831977 0.23061 # S4

1994 2 13 0.208271 0.25464 # S5
1995 2 13 0.202657 0.232678 # S5
1996 2 13 0.29486 0.219906 # S5
1997 2 13 0.459113 0.199639 # S5
1998 2 13 0.499113 0.207498 # S5
1999 2 13 0.557804 0.190297 # S5
2000 2 13 0.332073 0.203221 # S5
2001 2 13 0.690243 0.21287 # S5
2002 2 13 0.389268 0.225373 # S5
2003 2 13 0.222197 0.204888 # S5
2004 2 13 0.297345 0.2071 # S5
2005 2 13 0.248722 0.228862 # S5
2006 2 13 1.00752 0.192267 # S5
2007 2 13 0.690049 0.204015 # S5
2008 2 13 0.389985 0.212196 # S5
2009 2 13 0.69659 0.195183 # S5
2010 2 13 0.768759 0.198151 # S5
2011 2 13 0.514355 0.210665 # S5
2012 2 13 0.728556 0.197459 # S5
2013 2 13 0.213241 0.240291 # S5
2014 2 13 0.810052 0.4122 # S5
2006 3 14 3.20419 0.548688 # S6
2007 3 14 1.70947 0.513279 # S6
2008 3 14 7.64873 0.46797 # S6
2009 3 14 3.04584 0.471428 # S6
2010 3 14 5.43268 0.430134 # S6
2011 3 14 8.82981 0.496809 # S6
2012 3 14 4.87355 0.456906 # S6
2013 3 14 5.18471 0.455354 # S6
2014 3 14 1.73476 0.523049 # S6

0 #_N_fleets_with_discard
#_discard_units (1=same_as_catchunits(bio/num); 2=fraction; 3=numbers)
#_discard_errtype: >0 for DF of T-dist(read CV below); 0 for normal with CV; -1 for normal with se; -2 for lognormal
#Fleet Disc_units err_type
0 #N discard obs
#_year seas index obs err
#
0 #_N_meanbodywt_obs
30 #_DF_for_meanbodywt_T-distribution_like

2 # length bin method: 1=use databins; 2=generate from binwidth,min,max below; 3=read vector
1 # binwidth for population size comp
40 # minimum size in the population (lower edge of first bin and size at age 0.00)
310 # maximum size in the population (lower edge of last bin)

-1 #_comp_tail_compression
0.001 #_add_to_comp
0 #_combine males into females at or below this bin number
130 #_N_LengthBins
40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78 80 82 84 86 88 90 92 94 96 98 100 102 104 106 108 110 112 114 116 118 120 122
124 126 128 130 132 134 136 138 140 142 144 146 148 150 152 154 156 158 160 162 164 166 168 170 172 174 176 178 180 182 184 186 188
190 192 194 196 198 200 202 204 206 208 210 212 214 216 218 220 222 224 226 228 230 232 234 236 238 240 242 244 246 248 250 252 254
256 258 260 262 264 266 268 270 272 274 276 278 280 282 284 286 288 290 292 294 296 298
58 #_N_Length_obs
#Yr Seas Flt/Svy Gender Part Nsamp datavector(female-male)
1990 3 1 3 0 7 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 3 0 0 0 0 0 0 0 1 1 0 0 0 1 0 1 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 0 0 0 0 0 0 0 0 1 2 0 0 0 0 0 1 2 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
1990 4 1 3 0 6 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 1 1 1 0 0 1 2 0 0 1 2 3 1 2 1 6 2 4 2
0 2 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 1 0 1 1 7 6 1 3 2 2 1 7 3 6 1 3 1 1 0 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
1991 3 1 3 0 6 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 1 0 0 1 0 0 0 0 1 0 2 0 0 1 0 4 0 0 1 0 4 0 3 5 9 5 2 3 5 2 3 0 0 4 0 3 4 1 6 2 6 4 0 0 2 6 0 0
1 2 0 3 2 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2
0 0 0 1 2 0 1 0 0 0 0 0 2 2 1 2 0 0 2 1 3 2 2 0 2 9 6 6 1 5 2 3 2 0 0 4 0 0 0 0 2 3 2 4 2 2 1 1 1 2 3 0 1 2 0 2 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
1991 4 1 3 0 12 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 2 0 0 0 0 2 2 0 5 0 1 0 0 2
0 0 0 2 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 3 1 4 0 0 1 0 1 2 0 0 2 0 0 0 0 0 1 0 0 0 1 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
1992 3 1 3 0 11 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 2 0 0
1 1 0 0 1 1 2 4 0 0 0 0 1 0 0 0 2 0 0 0 0 0 0 0 0 0 0 1 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 1 0 0 0 0 0 0 0 0 0 0 0 0 0 2 2 0 0 0 4 0 3 0 2 0 0 2 2 2 0 2 0 2 0 4 2 4 0 6 6 0 0 0 2 0 4 0 2 2 4 4
2 0 0 0 2 0 2 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
1992 4 1 3 0 10 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 2 0 0 0 2 0 0 2 0 0 1 0 0 0 1 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 4 0 0 0 0 0 0 0 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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26 #_N_age_bins
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2 #_N_ageerror_definitions
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2.81094 2.98662 3.16231 3.33799 3.51367 3.68935 3.86504 4.04072 4.2164 4.39209
152 #_N_Agecomp_obs
3 #_Lbin_method: 1=poplenbins; 2=datalenbins; 3=lengths
1 #_combine males into females at or below this bin number
#Yr Seas Flt/Svy Gender Part Ageerr Lbin_lo Lbin_hi Nsamp datavector(female-male)
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0 #_N_MeanSize-at-Age_obs
#Yr Seas Flt/Svy Gender Part Ageerr Ignore datavector(female-male)
samplesize(female-male)

0 #_N_environ_variables
0 #_N_environ_obs
3 # N sizefreq methods to read
38 104 31 #Sizefreq N bins per method
2 2 2 #Sizetfreq units(bio/num) per method
3 3 3 #Sizefreq scale(kg/lbs/cm/inches) per method
0.001 0.001 0.001 #Sizefreq mincomp per method
33 13 7 #Sizefreq N obs per method
#_Sizefreq bins
40 47 54 61 68 75 82 89 96 103 110 117 124 131 138 145 152 159 166 173 180 187 194 201 208 215 222 229 236 243 250 257 264 271 278 285 292 299
40 94 96 98 100 102 104 106 108 110 112 114 116 118 120 122 124 126 128 130 132 134 136 138 140 142 144 146 148 150 152 154 156 158 160 162 164 166 168 170 172 174 176 178 180 182 184 186 188 190 192 194 196 198 200 202 204 206 208 210 212 214 216 218 220 222 224 226 228 230 232 234 236 238 240 242 244 246 248 250 252 254 256 258 260 262 264 266 268 270 272 274 276 278 280 282 284 286 288 290 292 294 296 298
40 96 103 110 117 124 131 138 145 152 159 166 173 180 187 194 201 208 215 222 229 236 243 250 257 264 271 278 285 292 299
#_Year season Fleet Gender Partition SampleSize <data>
1 1981 1 1 0 0 6 0 0 0 0 0 0 0 0 0 0 1 1 3 5 19 24 26 41 23 19 18 9 5 6 3 0 2 0 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
1 1981 3 1 0 0 22 0 0 0 0 4 3 3 1 0 1 1 4 3 3 3 1 5 6 6 8 11 6 3 14 2 1 2 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
1 1981 4 1 0 0 9 0 0 0 0 0 0 0 0 0 0 1 0 2 2 2 2 1 1 0 0 0 0 1 1 2 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
1 1982 1 1 0 0 13 0 0 0 0 0 0 0 1 2 4 2 7 6 17 20 25 25 28 29 16 15 11 2 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
1 1982 3 1 0 0 124 0 0 0 0 1 1 8 6 9 8 14 36 45 48 53 44 45 63 53 45 47 45 38 24 21 23 12 6 4 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
1 1982 4 1 0 0 17 0 0 0 0 0 1 0 0 1 0 1 3 7 8 8 16 9 10 9 4 6 4 1 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
1 1983 3 1 0 0 48 0 1 1 2 0 1 2 6 8 12 12 26 29 45 47 38 44 28 16 13 7 1 4 2 4 4 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

1 1983 4 1 0 0 65 0 0 1 4 15 23 20 12 5 5 4 3 1 12 18 24 23 22 15 14 4 4 2 2 0 0 1 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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1 1984 3 1 0 0 49 0 0 0 0 0 0 0 0 0 0 1 8 10 19 19 24 25 21 11 5 5 5 5 4 1 2 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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1 1984 4 1 0 0 45 0 0 0 0 0 0 1 2 0 5 5 8 8 13 14 16 20 12 10 3 1 3 0 1 2 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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1 1986 3 1 0 0 53 0 0 1 1 7 7 3 2 3 1 8 7 11 5 10 6 7 8 3 3 7 2 0 1 0 1 2 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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1 1986 4 1 0 0 37 0 0 0 0 3 12 11 19 22 20 32 34 39 39 35 35 26 11 8 3 3 0 2 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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1 1987 3 1 0 0 40 0 0 0 0 0 1 0 1 2 2 4 3 12 10 9 14 8 8 8 3 4 5 2 3 5 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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1 1987 4 1 0 0 18 0 0 0 0 2 4 6 8 13 28 31 31 18 8 4 5 2 1 2 3 0 1 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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1 1988 3 1 0 0 85 0 0 1 2 9 3 9 8 12 8 12 28 29 34 27 19 25 18 7 6 4 1 1 0 0 1 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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1 1988 4 1 0 0 60 0 0 0 0 2 0 5 4 21 20 15 25 29 30 27 34 51 33 30 13 13 2 2 1 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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1 1989 3 1 0 0 49 0 0 2 3 13 3 0 4 7 7 6 16 22 9 6 13 6 5 6 5 2 0 1 1 1 0 1 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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1 1989 4 1 0 0 55 0 0 0 3 17 41 55 48 60 69 72 70 75 32 37 34 23 14 14 11 3 4 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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1 1990 3 1 0 0 13 0 0 0 1 7 8 3 6 5 8 7 12 14 6 9 7 1 1 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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1 1981 2 2 0 0 27 0 0 1 5 3 4 8 8 24 29 38 40 57 45 46 61 68 73 89 51 41 24 10 9 11 7 7 5 6 0 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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1 1982 2 2 0 0 21 0 0 0 0 1 2 7 3 3 8 2 6 15 12 18 12 8 17 15 17 10 8 14 5 9 7 10 8 4 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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1 1983 2 2 0 0 65 0 1 0 4 5 3 5 14 11 16 31 41 56 78 76 102 102 97 69 40 31 31 24 16 25 10 18 6 11 5 7 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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1 1984 2 2 0 0 52 0 0 1 9 17 20 19 15 32 50 79 61 73 85 81 77 73 59 54 32 29 14 22 27 16 16 9 15 6 1 5 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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1 1985 2 2 0 0 75 0 0 3 17 15 4 25 55 50 52 44 50 56 67 68 66 53 35 29 21 18 14 24 23 20 15 10 5 9 4 5 2 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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1 1986 2 2 0 0 52 0 0 2 6 16 6 12 25 26 19 28 17 19 15 10 8 4 6 7 7 7 8 17 13 13 9 21 5 7 2 1 1 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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1 1987 2 2 0 0 39 0 0 0 0 0 0 8 18 38 29 29 44 29 18 17 8 5 6 2 1 4 9 17 26 27 20 19 11 6 6 3 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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1 1988 2 2 0 0 23 0 0 0 1 10 2 5 26 21 7 10 13 13 7 6 5 4 4 6 2 4 6 9 7 7 9 3 3 4 1 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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1 1989 2 2 0 0 9 0 0 0 0 0 0 2 10 15 18 28 26 30 20 15 17 1 2 5 1 3 1 0 2 2 0 1 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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1 2007 1 6 0 0 3 0 0 0 0 0 0 1 0 3 4 2 12 40 45 50 50 55 52 49 42 45 19 27 22 8 5 5 4 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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1 2007 3 6 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 1 2 10 20 25 28 29 27 17 14 6 1 2 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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1 2008 1 6 0 0 3 0 0 0 1 3 4 6 10 17 9 18 37 74 100 93 68 60 49 20 12 18 4 0 1 4 3 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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2 1990 3 3 3 0 8 5 1 1 0 2 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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2 1991 2 3 3 0 18 13 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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2 1991 3 3 3 0 9 8 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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2 1992 3 3 3 0 14 23 0 0 0 1 0 0 0 0 1 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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2 1993 1 3 3 0 17 4 1 1 2 2 1 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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2 1993 2 3 3 0 20 14 0 1 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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2 1993 3 3 3 0 16 9 0 0 0 0 2 1 1 2 1 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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2 1999 2 3 3 0 5 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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2 1999 3 3 3 0 6 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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3 1984 3 3 0 0 6 10 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
3 1986 2 3 0 0 13 21 4 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
3 1986 3 3 0 0 5 8 1 1 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
3 1987 2 3 0 0 9 25 3 3 0 1 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
3 1987 3 3 0 0 5 11 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
3 1988 2 3 0 0 6 20 2 1 3 2 0 1 0 0 0 2 0 0 1 0 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
3 1989 2 3 0 0 15 51 17 8 8 6 5 1 1 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

0 # do tags (0/1)

0 # no morphcomp data

999

ENDDATA

Control file

```
#V3.24U
#C 2015 thresher shark assessment
#_data_and_control_files: 2015_THR_dat.txt // 2015_THR_ctl.txt
#_SS-V3.24U-fast;_08/29/2014;_Stock_Synthesis_by_Richard_Methot_(NOAA)_using_ADMB_11.2_Linux64_compiled_on_RHEL6.6
1  #_N_Growth_Patterns
1 #_N_Morphs_Within_GrowthPattern
#_Cond 1 #_Morph_between/within_stdev_ratio (no read if N_morphs=1)
#_Cond  1 #vector_Morphdist_(-1_in_first_val_gives_normal_approx)
#
1 #  number of recruitment assignments (overrides GP*area*seas parameter values)
0 # recruitment interaction requested
#GP seas area for each recruitment assignment
 1 2 1
#
#_Cond 0 # N_movement_definitions goes here if N_areas > 1
#_Cond 1.0 # first age that moves (real age at begin of season, not integer) also cond on do_migration>0
#_Cond 1 1 1 2 4 10 # example move definition for seas=1, morph=1, source=1 dest=2, age1=4, age2=10
#
3 #_Nblock_Patterns
 5 3 1 #_blocks_per_pattern
# begin and end years of blocks
 1982 1984 1985 1988 1989 1991 1992 2000 2001 2014
 1982 1984 1985 1988 1989 2014
 1994 2014
#
0.5 #_fracfemale
0 #_natM_type:_0=1Parm; 1=N_breakpoints;_2=Lorenzen;_3=agespecific;_4=agespec_withseasinterpolate
  #_no additional input for selected M option; read 1P per morph
1 # GrowthModel: 1=vonBert with L1&L2; 2=Richards with L1&L2; 3=age_speciific_K; 4=not implemented
0.125 #_Growth_Age_for_L1
999 #_Growth_Age_for_L2 (999 to use as Linf)
0 #_SD_add_to_LAA (set to 0.1 for SS2 V1.x compatibility)
0 #_CV_Growth_Pattern:  0 CV=f(LAA); 1 CV=F(A); 2 SD=F(LAA); 3 SD=F(A); 4 logSD=F(A)
3 #_maturity_option:  1=length logistic; 2=age logistic; 3=read age-maturity by GP; 4=read age-fecundity by GP; 5=read fec and wt from wtatage.ss; 6=read length-maturity by GP
#_Age_Maturity by growth pattern for females
 0 0 0 0 0 0.5 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
5 #_First_Mature_Age
2 #_fecundity option:(1)eggs=Wt*(a+b*Wt);(2)eggs=a*L^b;(3)eggs=a*Wt^b; (4)eggs=a+b*L; (5)eggs=a+b*W
0 #_hermaphroditism option:  0=none; 1=age-specific fxn
2 #_parameter_offset_approach (1=none, 2= M, G, CV_G as offset from female-GP1, 3=like SS2 V1.x)
1 #_env/block/dev_adjust_method (1=standard; 2=logistic transform keeps in base parm bounds; 3=standard w/ no bound check)
#
#_growth_parms
#_LO HI INIT PRIOR PR_type SD PHASE env-var use_dev dev_minyr dev_maxyr dev_stddev Block Block_Fxn
 0.05 0.8 0.179 0.179 -1 99 -1 0 0 0 0 0 0 0 # NatM_p_1_Fem_GP_1
 30 100 71.2608 85.2 -1 99 5 0 0 0 0 0 0 0 # L_at_Amin_Fem_GP_1
 200 300 251.924 246.6 -1 99 5 0 0 0 0 0 0 0 # L_at_Amax_Fem_GP_1
 0 0.2 0.128605 0.124 -1 99 5 0 0 0 0 0 0 0 # VonBert_K_Fem_GP_1
 0.001 0.3 0.08 0.1 -1 99 -5 0 0 0 0 0 0 0 # CV_young_Fem_GP_1
 0.001 0.3 0.05 0.05 -1 99 -6 0 0 0 0 0 0 0 # CV_old_Fem_GP_1
 0 0 0 0.179 -1 99 -1 0 0 0 0 0 0 0 # NatM_p_1_Mal_GP_1
 -2 2 0.00443294 74 -1 99 5 0 0 0 0 0 0 0 # L_at_Amin_Mal_GP_1
 -2 2 -0.0118114 221.6 -1 99 5 0 0 0 0 0 0 0 # L_at_Amax_Mal_GP_1
 -2 2 -0.02332 0.189 -1 99 5 0 0 0 0 0 0 0 # VonBert_K_Mal_GP_1
 0 0 0 0.1 -1 99 -5 0 0 0 0 0 0 0 # CV_young_Mal_GP_1
 0 0 0 0.05 -1 99 -6 0 0 0 0 0 0 0 # CV_old_Mal_GP_1
 0 2 0.000188 0.000188 -1 99 -3 0 0 0 0 0 0 0 # Wtlen_1_Fem
 1 4 2.5188 2.5188 -1 99 -3 0 0 0 0 0 0 0 # Wtlen_2_Fem
```

```
 1 10 5 5 -1 99 -3 0 0 0 0 0 0 0 # Mat50%_Fem
 -5 0 -3 -3 -1 99 -3 0 0 0 0 0 0 0 # Mat_slope_Fem
 0 5 4 3 -1 99 -3 0 0 0 0 0 0 0 # Eggs_scalar_Fem
 -1 3 0 0 -1 99 -3 0 0 0 0 0 0 0 # Eggs_exp_len_Fem
 0 2 0.000188 0.000188 -1 99 -3 0 0 0 0 0 0 0 # Wtlen_1_Mal
 1 4 2.5188 2.5188 -1 99 -3 0 0 0 0 0 0 0 # Wtlen_2_Mal
 -4 4 0 0 -1 99 -3 0 0 0 0 0 0 0 # RecrDist_GP_1
 -4 4 0 0 -1 99 -3 0 0 0 0 0 0 0 # RecrDist_Area_1
 -4 4 -4 -4 -1 99 -3 0 0 0 0 0 0 0 # RecrDist_Seas_1
 -4 4 0 0 -1 99 -3 0 0 0 0 0 0 0 # RecrDist_Seas_2
 -4 4 -4 -4 -1 99 -3 0 0 0 0 0 0 0 # RecrDist_Seas_3
 -4 4 -4 -4 -1 99 -3 0 0 0 0 0 0 0 # RecrDist_Seas_4
 -4 4 1 1 -1 99 -3 0 0 0 0 0 0 0 # CohortGrowDev
#
#_Cond 0  #custom_MG-env_setup (0/1)
#_Cond -2 2 0 0 -1 99 -2 #_placeholder when no MG-environ parameters
#
#_Cond 0  #custom_MG-block_setup (0/1)
#_Cond -2 2 0 0 -1 99 -2 #_placeholder when no MG-block parameters
#_Cond No MG parm trends
#
#_seasonal_effects_on_biology_parms
 0 0 0 0 0 0 0 0 0 0 #_femwtlen1,femwtlen2,mat1,mat2,fec1,fec2,Malewtlen1,malewtlen2,L1,K
#_Cond -2 2 0 0 -1 99 -2 #_placeholder when no seasonal MG parameters
#
#_Cond -4 #_MGparm_Dev_Phase
#
#_Spawner-Recruitment
7 #_SR_function: 2=Ricker; 3=std_B-H; 4=SCAA; 5=Hockey; 6=B-H_flattop; 7=survival_3Parm; 8=Shepard_3Parm
#_LO HI INIT PRIOR PR_type SD PHASE
 1 15 4.34499 7 -1 99 1 # SR_LN(R0)
 0 1 0.6 0.5 -1 99 -7 # SR_surv_Sfrac
 0.4 7 3.0592 5 -1 99 1 # SR_surv_Beta
 0 2 0.5 0.5 -1 99 -1 # SR_sigmaR
 -5 5 0 0 -1 99 -1 # SR_envlink
 -4 4 0 0 -999 99 -1 # SR_R1_offset
 0 0 0 0 -1 99 -1 # SR_autocorr
0 #_SR_env_link
0 #_SR_env_target_0=none;1=devs;_2=R0;_3=steepness
1 #do_recdev:  0=none; 1=devvector; 2=simple deviations
1969 # first year of main recr_devs; early devs can preceed this era
2014 # last year of main recr_devs; forecast devs start in following year
1 #_recdev phase
1 # (0/1) to read 13 advanced options
 0 #_recdev_early_start (0=none; neg value makes relative to recdev_start)
 -4 #_recdev_early_phase
 0 #_forecast_recruitment phase (incl. late recr) (0 value resets to maxphase+1)
 1 #_lambda for Fcast_recr_like occurring before endyr+1
 1972.58 #_last_early_yr_nobias_adj_in_MPD
 1980.7 #_first_yr_fullbias_adj_in_MPD
 2012.08 #_last_yr_fullbias_adj_in_MPD
 2018.25 #_first_recent_yr_nobias_adj_in_MPD
 0.8192 #_max_bias_adj_in_MPD (-1 to override ramp and set biasadj=1.0 for all estimated recdevs)
 0 #_period of cycles in recruitment (N parms read below)
 -5 #min rec_dev
 5 #max rec_dev
 0 #_read_recdevs
#_end of advanced SR options
#
#_placeholder for full parameter lines for recruitment cycles
# read specified recr devs
```

#_Yr Input_value
#
all recruitment deviations
#DisplayOnly 0.228566 # Main_RecrDev_1969
#DisplayOnly 0.273254 # Main_RecrDev_1970
#DisplayOnly 0.247473 # Main_RecrDev_1971
#DisplayOnly 0.123546 # Main_RecrDev_1972
#DisplayOnly -0.0136806 # Main_RecrDev_1973
#DisplayOnly -0.0771674 # Main_RecrDev_1974
#DisplayOnly -0.10308 # Main_RecrDev_1975
#DisplayOnly -0.200984 # Main_RecrDev_1976
#DisplayOnly -0.393457 # Main_RecrDev_1977
#DisplayOnly -0.476102 # Main_RecrDev_1978
#DisplayOnly -0.190753 # Main_RecrDev_1979
#DisplayOnly -0.255826 # Main_RecrDev_1980
#DisplayOnly -0.356712 # Main_RecrDev_1981
#DisplayOnly -0.380224 # Main_RecrDev_1982
#DisplayOnly 0.0529326 # Main_RecrDev_1983
#DisplayOnly -0.183046 # Main_RecrDev_1984
#DisplayOnly -0.0141641 # Main_RecrDev_1985
#DisplayOnly 0.00661811 # Main_RecrDev_1986
#DisplayOnly 0.0561474 # Main_RecrDev_1987
#DisplayOnly -0.15337 # Main_RecrDev_1988
#DisplayOnly -0.383337 # Main_RecrDev_1989
#DisplayOnly -0.184369 # Main_RecrDev_1990
#DisplayOnly -0.098193 # Main_RecrDev_1991
#DisplayOnly 0.226842 # Main_RecrDev_1992
#DisplayOnly 0.116272 # Main_RecrDev_1993
#DisplayOnly -0.215973 # Main_RecrDev_1994
#DisplayOnly -0.119692 # Main_RecrDev_1995
#DisplayOnly 0.235584 # Main_RecrDev_1996
#DisplayOnly 0.317426 # Main_RecrDev_1997
#DisplayOnly 0.256081 # Main_RecrDev_1998
#DisplayOnly 0.465279 # Main_RecrDev_1999
#DisplayOnly 0.0998961 # Main_RecrDev_2000
#DisplayOnly 0.730913 # Main_RecrDev_2001
#DisplayOnly 0.121975 # Main_RecrDev_2002
#DisplayOnly -0.505468 # Main_RecrDev_2003
#DisplayOnly -0.227223 # Main_RecrDev_2004
#DisplayOnly -0.47988 # Main_RecrDev_2005
#DisplayOnly 0.567074 # Main_RecrDev_2006
#DisplayOnly 0.355006 # Main_RecrDev_2007
#DisplayOnly 0.0090772 # Main_RecrDev_2008
#DisplayOnly 0.27824 # Main_RecrDev_2009
#DisplayOnly 0.336999 # Main_RecrDev_2010
#DisplayOnly -0.027596 # Main_RecrDev_2011
#DisplayOnly 0.38719 # Main_RecrDev_2012
#DisplayOnly -0.570802 # Main_RecrDev_2013
#DisplayOnly 0.118709 # Main_RecrDev_2014
#
#Fishing Mortality info
0.1 # F ballpark for annual F (=Z-M) for specified year
-2008 # F ballpark year (neg value to disable)
3 # F_Method: 1=Pope; 2=instan. F; 3=hybrid (hybrid is recommended)
4 # max F or harvest rate, depends on F_Method
no additional F input needed for Fmethod 1
if Fmethod=2; read overall start F value; overall phase; N detailed inputs to read
if Fmethod=3; read N iterations for tuning for Fmethod 3
5 # N iterations for tuning F in hybrid method (recommend 3 to 7)
#
#_initial_F_parms

```
#_LO HI INIT PRIOR PR_type SD PHASE
 0 3 0.0238448 0 -1 99 1 # InitF_1F1
 0 1 0 0 -1 99 -1 # InitF_2F2
 0 1 0 0 -1 99 -1 # InitF_3F3
 0 3 0.0222067 0 -1 99 1 # InitF_4F4
 0 1 0 0 -1 99 -1 # InitF_5F5
 0 1 0 0 -1 99 -1 # InitF_6F6
 0 1 0 0 -1 99 -1 # InitF_7F7
 0 3 0.0444701 0 -1 99 1 # InitF_8F8
#
#_Q_setup
 # Q_type options:  <0=mirror, 0=float_nobiasadj, 1=float_biasadj, 2=parm_nobiasadj, 3=parm_w_random_dev, 4=parm_w_randwalk,
5=mean_unbiased_float_assign_to_parm
#_for_env-var:_enter_index_of_the_env-var_to_be_linked
#_Den-dep  env-var  extra_se  Q_type
 0 0 0 0 # 1 F1
 0 0 0 0 # 2 F2
 0 0 0 0 # 3 F3
 0 0 0 0 # 4 F4
 0 0 0 0 # 5 F5
 0 0 0 0 # 6 F6
 0 0 0 0 # 7 F7
 0 0 0 0 # 8 F8
 0 0 0 0 # 9 S1
 0 0 0 0 # 10 S2
 0 0 0 0 # 11 S3
 0 0 0 0 # 12 S4
 0 0 0 0 # 13 S5
 0 0 0 0 # 14 S6
#
#_Cond 0 #_If q has random component, then 0=read one parm for each fleet with random q; 1=read a parm for each year of index
#_Q_parms(if_any);Qunits_are_ln(q)
#
#_size_selex_types
#discard_options:_0=none;_1=define_retention;_2=retention&mortality;_3=all_discarded_dead
#_Pattern Discard Male Special
 24 0 0 0 # 1 F1
 27 0 0 4 # 2 F2
 0 0 0 0 # 3 F3
 15 0 0 1 # 4 F4
 15 0 0 2 # 5 F5
 15 0 0 1 # 6 F6
 15 0 0 2 # 7 F7
 24 0 0 0 # 8 F8
 15 0 0 1 # 9 S1
 15 0 0 1 # 10 S2
 15 0 0 1 # 11 S3
 0 0 0 0 # 12 S4
 0 0 0 0 # 13 S5
 24 0 0 0 # 14 S6
#
#_age_selex_types
#_Pattern ___ Male Special
 11 0 0 0 # 1 F1
 11 0 0 0 # 2 F2
 14 0 0 0 # 3 F3
 11 0 0 0 # 4 F4
 11 0 0 0 # 5 F5
 11 0 0 0 # 6 F6
 11 0 0 0 # 7 F7
 11 0 0 0 # 8 F8
```

11 0 0 0 # 9 S1
11 0 0 0 # 10 S2
11 0 0 0 # 11 S3
15 0 0 3 # 12 S4
15 0 0 3 # 13 S5
11 0 0 0 # 14 S6
#_LO HI INIT PRIOR PR_type SD PHASE env-var use_dev dev_minyr dev_maxyr dev_stddev Block Block_Fxn
45 250 156.911 150 -1 99 2 0 0 0 0 0 1 2 # SizeSel_1P_1_F1
-4 9 -4 1 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_1P_2_F1
-4 12 6.49387 3 -1 99 3 0 0 0 0 0 1 2 # SizeSel_1P_3_F1
-4 9 8.07035 3 -1 99 3 0 0 0 0 0 1 2 # SizeSel_1P_4_F1
-9 9 -2.24779 0 -1 99 4 0 0 0 0 0 1 2 # SizeSel_1P_5_F1
-1000 -1000 -1000 0 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_1P_6_F1
0 2 0 150 -1 99 -99 0 0 0 0 0 0 0 # SizeSpline_Code_F2_2
-1 1 0.0670299 1 -1 99 3 0 0 0 0 0 0 0 # SizeSpline_GradLo_F2_2
-1 1 -0.0659269 3 -1 99 3 0 0 0 0 0 0 0 # SizeSpline_GradHi_F2_2
45 250 75 3 -1 99 -99 0 0 0 0 0 0 0 # SizeSpline_Knot_1_F2_2
45 250 125 3 -1 99 -99 0 0 0 0 0 0 0 # SizeSpline_Knot_2_F2_2
45 250 175 3 -1 99 -99 0 0 0 0 0 0 0 # SizeSpline_Knot_3_F2_2
45 250 225 3 -1 99 -99 0 0 0 0 0 0 0 # SizeSpline_Knot_4_F2_2
-9 9 -3.13397 3 -1 99 3 0 0 0 0 0 2 2 # SizeSpline_Val_1_F2_2
-9 9 -0.579033 3 -1 99 3 0 0 0 0 0 2 2 # SizeSpline_Val_2_F2_2
-9 9 0 3 -1 99 -3 0 0 0 0 0 0 0 # SizeSpline_Val_3_F2_2
-9 9 -3.1004 3 -1 99 3 0 0 0 0 0 2 2 # SizeSpline_Val_4_F2_2
45 250 79.5632 80 -1 99 2 0 0 0 0 0 0 0 # SizeSel_8P_1_F8
-4 9 -4 0 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_8P_2_F8
-4 9 4.13469 3 -1 99 3 0 0 0 0 0 0 0 # SizeSel_8P_3_F8
-4 9 6.73305 3 -1 99 3 0 0 0 0 0 0 0 # SizeSel_8P_4_F8
-1000 -1000 -1000 -1000 -1 99 -2 0 0 0 0 0 0 0 # SizeSel_8P_5_F8
-1000 -1000 -1000 -1000 -1 99 -2 0 0 0 0 0 0 0 # SizeSel_8P_6_F8
45 250 84.7435 80 -1 99 2 0 0 0 0 0 0 0 # SizeSel_14P_1_S6
-4 9 -4 0 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_14P_2_S6
-4 9 5.09989 3 -1 99 3 0 0 0 0 0 0 0 # SizeSel_14P_3_S6
-4 9 7.77898 3 -1 99 3 0 0 0 0 0 0 0 # SizeSel_14P_4_S6
-1000 -1000 -1000 -1000 -1 99 -2 0 0 0 0 0 0 0 # SizeSel_14P_5_S6
-1000 -1000 -1000 -1000 -1 99 -2 0 0 0 0 0 0 0 # SizeSel_14P_6_S6
0 10 0.1 0.1 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_1P_1_F1
10 30 25 25 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_1P_2_F1
0 10 0.1 0.1 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_2P_1_F2
10 30 25 25 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_2P_2_F2
-9 9 5.82464 0 -1 99 2 0 0 0 0 0 3 2 # AgeSel_3P_1_F3
-9 9 -3.62717 0 -1 99 2 0 0 0 0 0 3 2 # AgeSel_3P_2_F3
-9 9 -4.35722 0 -1 99 2 0 0 0 0 0 3 2 # AgeSel_3P_3_F3
-99 9 -99 0 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_3P_4_F3
-99 9 -99 0 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_3P_5_F3
-99 9 -99 0 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_3P_6_F3
-99 9 -99 0 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_3P_7_F3
-99 9 -99 0 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_3P_8_F3
-99 9 -99 0 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_3P_9_F3
-99 9 -99 0 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_3P_10_F3
-99 9 -99 0 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_3P_11_F3
-99 9 -99 0 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_3P_12_F3
-99 9 -99 0 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_3P_13_F3
-99 9 -99 0 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_3P_14_F3
-99 9 -99 0 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_3P_15_F3
-99 9 -99 0 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_3P_16_F3
-99 9 -99 0 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_3P_17_F3
-99 9 -99 0 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_3P_18_F3
-99 9 -99 0 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_3P_19_F3
-99 9 -99 0 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_3P_20_F3
-99 9 -99 0 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_3P_21_F3

-99 9 -99 0 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_3P_22_F3
-99 9 -99 0 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_3P_23_F3
-99 9 -99 0 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_3P_24_F3
-99 9 -99 0 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_3P_25_F3
-99 9 -99 0 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_3P_26_F3
0 10 0.1 0.1 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_4P_1_F4
10 30 25 25 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_4P_2_F4
0 10 0.1 0.1 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_5P_1_F5
10 30 25 25 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_5P_2_F5
0 10 0.1 0.1 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_6P_1_F6
10 30 25 25 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_6P_2_F6
0 10 0.1 0.1 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_7P_1_F7
10 30 25 25 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_7P_2_F7
0 10 0.1 0.1 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_8P_1_F8
10 30 25 25 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_8P_2_F8
0 10 0.1 0.1 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_9P_1_S1
10 30 25 25 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_9P_2_S1
0 10 0.1 0.1 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_10P_1_S2
10 30 25 25 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_10P_2_S2
0 10 0.1 0.1 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_11P_1_S3
10 30 25 25 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_11P_2_S3
0 10 0.1 0.1 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_14P_1_S6
10 30 25 25 -1 99 -2 0 0 0 0 0 0 0 # AgeSel_14P_2_S6
#_Cond 0 #_custom_sel-env_setup (0/1)
#_Cond -2 2 0 0 -1 99 -2 #_placeholder when no enviro fxns
1 #_custom_sel-blk_setup (0/1)
45 250 154.333 150 -1 99 5 # SizeSel_1P_1_F1_BLK1repl_1982
45 250 137.941 150 -1 99 5 # SizeSel_1P_1_F1_BLK1repl_1985
45 250 130.305 150 -1 99 5 # SizeSel_1P_1_F1_BLK1repl_1989
45 250 160.807 150 -1 99 5 # SizeSel_1P_1_F1_BLK1repl_1992
45 250 163.568 150 -1 99 5 # SizeSel_1P_1_F1_BLK1repl_2001
-4 12 6.36891 3 -1 99 5 # SizeSel_1P_3_F1_BLK1repl_1982
-4 12 6.61094 3 -1 99 5 # SizeSel_1P_3_F1_BLK1repl_1985
-4 12 6.57527 3 -1 99 5 # SizeSel_1P_3_F1_BLK1repl_1989
-4 12 6.58495 3 -1 99 5 # SizeSel_1P_3_F1_BLK1repl_1992
-4 12 6.7557 3 -1 99 5 # SizeSel_1P_3_F1_BLK1repl_2001
-9 9 7.43762 0 -1 99 6 # SizeSel_1P_4_F1_BLK1repl_1982
-9 9 7.9974 0 -1 99 6 # SizeSel_1P_4_F1_BLK1repl_1985
-9 9 7.88338 0 -1 99 6 # SizeSel_1P_4_F1_BLK1repl_1989
-9 9 7.52408 0 -1 99 6 # SizeSel_1P_4_F1_BLK1repl_1992
-9 9 7.27887 0 -1 99 6 # SizeSel_1P_4_F1_BLK1repl_2001
-9 9 -2.42415 0 -1 99 6 # SizeSel_1P_5_F1_BLK1repl_1982
-9 9 -1.47418 0 -1 99 6 # SizeSel_1P_5_F1_BLK1repl_1985
-9 9 0.235937 0 -1 99 6 # SizeSel_1P_5_F1_BLK1repl_1989
-9 9 -4.05288 0 -1 99 6 # SizeSel_1P_5_F1_BLK1repl_1992
-9 9 -3.86467 0 -1 99 6 # SizeSel_1P_5_F1_BLK1repl_2001
-9 9 -3.26024 3 -1 99 6 # SizeSpline_Val_1_F2_2_BLK2repl_1982
-9 9 -1.09079 3 -1 99 6 # SizeSpline_Val_1_F2_2_BLK2repl_1985
-9 9 -1.71958 3 -1 99 6 # SizeSpline_Val_1_F2_2_BLK2repl_1989
-9 9 -0.738698 3 -1 99 6 # SizeSpline_Val_2_F2_2_BLK2repl_1982
-9 9 0.101155 3 -1 99 6 # SizeSpline_Val_2_F2_2_BLK2repl_1985
-9 9 0.980473 3 -1 99 6 # SizeSpline_Val_2_F2_2_BLK2repl_1989
-9 9 -1.93409 3 -1 99 6 # SizeSpline_Val_4_F2_2_BLK2repl_1982
-9 9 0.078129 3 -1 99 6 # SizeSpline_Val_4_F2_2_BLK2repl_1985
-9 9 -1.28522 3 -1 99 6 # SizeSpline_Val_4_F2_2_BLK2repl_1989
-9 9 6.98104 0 -1 99 6 # AgeSel_3P_1_F3_BLK3repl_1994
-9 9 -5.6965 0 -1 99 6 # AgeSel_3P_2_F3_BLK3repl_1994
-9 9 -5.27026 0 -1 99 6 # AgeSel_3P_3_F3_BLK3repl_1994
#_Cond No selex parm trends
#_Cond -4 # placeholder for selparm_Dev_Phase
1 #_env/block/dev_adjust_method (1=standard; 2=logistic trans to keep in base parm bounds; 3=standard w/ no bound check)

```
#
# Tag loss and Tag reporting parameters go next
0  # TG_custom:  0=no read; 1=read if tags exist
#_Cond -6 6 1 1 2 0.01 -4 0 0 0 0 0 0 0  #_placeholder if no parameters
#
1 #_Variance_adjustments_to_input_values
#_fleet: 1 2 3 4 5 6 7 8 9 10 11 12 13 14
  0 0 0 0 0 0 0 0 0 0.26636 0.332445 0 0 0 #_add_to_survey_CV
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 #_add_to_discard_stddev
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 #_add_to_bodywt_CV
  1 1 1 1 1 1 1 1 1 1 1 1 1 1 #_mult_by_lencomp_N
  1 1 1 1 1 1 1 1 1 1 1 1 1 1 #_mult_by_agecomp_N
  1 1 1 1 1 1 1 1 1 1 1 1 1 1 #_mult_by_size-at-age_N
#
10 #_maxlambdaphase
1 #_sd_offset
#
25 # number of changes to make to default Lambdas (default value is 1.0)
# Like_comp codes:  1=surv; 2=disc; 3=mnwt; 4=length; 5=age; 6=SizeFreq; 7=sizeage; 8=catch; 9=init_equ_catch;
# 10=recrdev; 11=parm_prior; 12=parm_dev; 13=CrashPen; 14=Morphcomp; 15=Tag-comp; 16=Tag-negbin; 17=F_ballpark
#like_comp fleet/survey  phase  value  sizefreq_method
 1 9 1 1 0
 1 10 1 1 0
 1 11 1 1 0
 1 12 1 1 0
 1 13 1 1 0
 1 14 1 0 0
 4 1 1 1 0
 4 2 1 1 0
 4 8 1 1 0
 4 14 1 1 0
 5 1 1 0.2 0
 5 3 1 0.2 0
 6 1 1 1 1
 6 2 1 1 1
 6 3 1 1 2
 6 3 1 1 3
 6 6 1 0 1
 9 1 1 1 0
 9 2 1 0 0
 9 3 1 0 0
 9 4 1 1 0
 9 5 1 0 0
 9 6 1 0 0
 9 7 1 0 0
 9 8 1 1 0
#
# lambdas (for info only; columns are phases)
#  0 0 0 0 0 0 0 0 0 0 #_CPUE/survey:_1
#  0 0 0 0 0 0 0 0 0 0 #_CPUE/survey:_2
#  0 0 0 0 0 0 0 0 0 0 #_CPUE/survey:_3
#  0 0 0 0 0 0 0 0 0 0 #_CPUE/survey:_4
#  0 0 0 0 0 0 0 0 0 0 #_CPUE/survey:_5
#  0 0 0 0 0 0 0 0 0 0 #_CPUE/survey:_6
#  0 0 0 0 0 0 0 0 0 0 #_CPUE/survey:_7
#  0 0 0 0 0 0 0 0 0 0 #_CPUE/survey:_8
#  1 1 1 1 1 1 1 1 1 1 #_CPUE/survey:_9
#  1 1 1 1 1 1 1 1 1 1 #_CPUE/survey:_10
#  1 1 1 1 1 1 1 1 1 1 #_CPUE/survey:_11
#  1 1 1 1 1 1 1 1 1 1 #_CPUE/survey:_12
#  1 1 1 1 1 1 1 1 1 1 #_CPUE/survey:_13
```

```
#  0 0 0 0 0 0 0 0 0 0 #_CPUE/survey:_14
#  1 1 1 1 1 1 1 1 1 1 #_lencomp:_1
#  1 1 1 1 1 1 1 1 1 1 #_lencomp:_2
#  0 0 0 0 0 0 0 0 0 0 #_lencomp:_3
#  0 0 0 0 0 0 0 0 0 0 #_lencomp:_4
#  0 0 0 0 0 0 0 0 0 0 #_lencomp:_5
#  0 0 0 0 0 0 0 0 0 0 #_lencomp:_6
#  0 0 0 0 0 0 0 0 0 0 #_lencomp:_7
#  1 1 1 1 1 1 1 1 1 1 #_lencomp:_8
#  0 0 0 0 0 0 0 0 0 0 #_lencomp:_9
#  0 0 0 0 0 0 0 0 0 0 #_lencomp:_10
#  0 0 0 0 0 0 0 0 0 0 #_lencomp:_11
#  0 0 0 0 0 0 0 0 0 0 #_lencomp:_12
#  0 0 0 0 0 0 0 0 0 0 #_lencomp:_13
#  1 1 1 1 1 1 1 1 1 1 #_lencomp:_14
#  0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 #_agecomp:_1
#  0 0 0 0 0 0 0 0 0 0 #_agecomp:_2
#  0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 #_agecomp:_3
#  0 0 0 0 0 0 0 0 0 0 #_agecomp:_4
#  0 0 0 0 0 0 0 0 0 0 #_agecomp:_5
#  0 0 0 0 0 0 0 0 0 0 #_agecomp:_6
#  0 0 0 0 0 0 0 0 0 0 #_agecomp:_7
#  0 0 0 0 0 0 0 0 0 0 #_agecomp:_8
#  0 0 0 0 0 0 0 0 0 0 #_agecomp:_9
#  0 0 0 0 0 0 0 0 0 0 #_agecomp:_10
#  0 0 0 0 0 0 0 0 0 0 #_agecomp:_11
#  0 0 0 0 0 0 0 0 0 0 #_agecomp:_12
#  0 0 0 0 0 0 0 0 0 0 #_agecomp:_13
#  0 0 0 0 0 0 0 0 0 0 #_agecomp:_14
#  1 1 1 1 1 1 1 1 1 1 #_sizefreq:_1
#  1 1 1 1 1 1 1 1 1 1 #_sizefreq:_2
#  1 1 1 1 1 1 1 1 1 1 #_sizefreq:_3
#  1 1 1 1 1 1 1 1 1 1 #_sizefreq:_4
#  0 0 0 0 0 0 0 0 0 0 #_sizefreq:_5
#  1 1 1 1 1 1 1 1 1 1 #_init_equ_catch
#  1 1 1 1 1 1 1 1 1 1 #_recruitments
#  1 1 1 1 1 1 1 1 1 1 #_parameter-priors
#  1 1 1 1 1 1 1 1 1 1 #_parameter-dev-vectors
#  1 1 1 1 1 1 1 1 1 1 #_crashPenLambda
#  0 0 0 0 0 0 0 0 0 0 # F_ballpark_lambda
0 # (0/1) read specs for more stddev reporting
 # 0 1 -1 5 1 5 1 -1 5 # placeholder for selex type, len/age, year, N selex bins, Growth pattern, N growth ages, NatAge_area(-1 for all), NatAge_yr, N Natages
 # placeholder for vector of selex bins to be reported
 # placeholder for vector of growth ages to be reported
 # placeholder for vector of NatAges ages to be reported
999
```